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Research and Development

Workshop on Indoor Air Quality Research Needs

Interagency Research Group on Indoor Air Quality

Interagency Energy/Environment R&D Program Report

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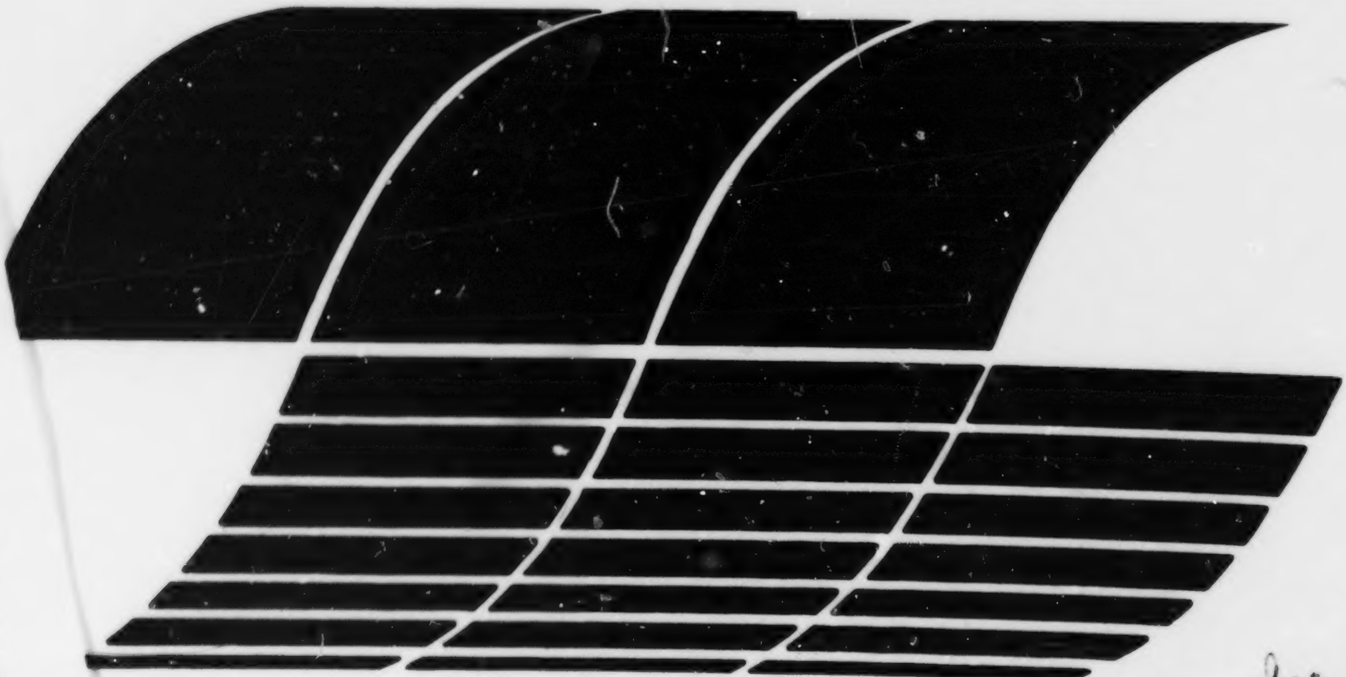

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Foreword

A group of experts and members of the interested public met on December 3-5, 1980 in an open Workshop on Indoor Air Quality Research Needs. The Workshop was planned and sponsored by the Interagency Research Group on Indoor Air Quality (IRG on IAQ), whose members include representatives of several departments and agencies, including Department of Housing and Urban Development, Department of Health and Human Services, Consumer Produce Safety Commission, Environmental Protection Agency, Department of Energy, Department of Defense, Department of Labor, Department of Commerce, and Department of Interior.

The more than 200 workshop participants were given three responsibilities: (1) to delineate the state-of-the-art of knowledge about indoor air quality and to outline future research needs; (2) to comment on a general "Strategy for Indoor Air Quality Research" drafted by the IRG on IAQ; (3) to describe ongoing research efforts for inclusion in an "Inventory" document on Federal and private research in the field. The present document contains the Workshop report; the "Inventory" and the "Strategy" will be published separately.

The Workshop report will be used as the basis for setting priorities within a detailed research and development plan for Federal activities in indoor air quality. The R&D plan will be written in the coming months by the IRG on IAQ: it is believed that, through such collaborative efforts, unnecessary and duplicative projects can be avoided and researchers can benefit more readily from others' experience.

The emergence of indoor air pollution as a national issue was long overdue. Participants reported that the average American spends upwards of 90 percent of his or her time indoors. The elderly, the infirm, the very young, and other most-at-risk groups spend a greater fraction of their time indoors. Participants reported that, increasingly, research results suggest that indoor exposures to several major pollutant classes dominate human exposure in the United States. As a result of these and other points, most workshop participants expressed their feeling that indoor air pollution will become a major focus of new environment-related research efforts in the 1980's.

As co-chairpersons of the Workshop and of the IRG on IAQ we would like to express our gratitude and admiration to all of the participants for their contributions to the success of the Workshop, and especially to the panel members who drafted this report. Additionally, we would like to note the fine organizational efforts of GEOMET, led by Demetrios Moschandreas and Jeannie Riordan, in administering the Workshop and in preparing this report.

Howard Ross
Co-Chairperson
Department of Energy

David Berg
David Berg
Co-Chairperson
Environmental Protection Agency

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EXECUTIVE SUMMARY

The Interagency Research Group (IRG) on Indoor Air Quality is a continuously functioning body established to bring together Federal Agencies concerned with research on the indoor environment. Agencies actively participating include the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), U.S. Department of Housing and Urban Development (HUD), Consumer Product Safety Commission (CPSC), Centers for Disease Control (CDC), National Institute for Occupational Safety and Health (NIOSH), National Institute of Environmental Health Sciences (NIEHS), Occupational Safety and Health Administration (OSHA), National Bureau of Standards (NBS), U.S. Department of Defense (DOD), Coast Guard, Bureau of Mines, and National Science Foundation.

The IRG has undertaken to (1) prepare an inventory of ongoing and recently completed research on indoor air quality; (2) draft a research strategy; (3) develop a preliminary research agenda; and (4) organize a workshop to broaden the technical base for information on items (1), (2), and (3). To facilitate meeting these responsibilities, the IRG established five working groups of Federal experts in the following technical areas: (1) monitoring and characterization; (2) instrumentation; (3) health effects; (4) controls; and (5) risk analysis. Each group has the ongoing responsibility of assisting the IRG in the appropriate area.

A smaller interagency Workshop Steering Group (WSG), consisting of representatives from EPA, DOE, HUD, CPSC, and NIOSH, organized a national Workshop on Indoor Air Quality Research Needs to solicit expert review and public comment on: (1) the draft strategy plan and (2) indoor air quality research needs and objectives. Preparatory materials on these two items and other relevant information generated by the WSG and the working groups (including a sixth group, on Radon and Radon Progeny) were compiled in a briefing book. The sixth group was established specifically for the workshop to examine for one class of pollutants information contributed by all of the technical areas.

The Workshop on Indoor Air Quality Research Needs was held in Leesburg, Virginia, on December 3-5, 1980. Specific objectives included:

- Defining the research agenda necessary to obtain a sufficient understanding of indoor air quality pollutants, sources, measurement methods and instruments, controls, and risks
- Completing a state-of-the-art review of knowledge on indoor air quality
- Completing an inventory of recent and ongoing research (Federal and non-Federal) related to indoor air quality
- Commenting on the research strategy for indoor air quality.

A multidisciplinary group of about 200 U.S. and Canadian technical, scientific, and policy experts representing the Federal, public, and private industry sectors was assembled.

The workshop was comprised of an orderly sequence of plenary and concurrent technical sessions. Four technical sessions corresponded to the working groups on monitoring, instrumentation, health effects, and controls. The topic of the fifth working group, Risk Assessment, was addressed in a plenary session. The subject of Radon and Radon Progeny in indoor environments was also addressed at a plenary session as a case study. Each session was led by a panel of nationally known experts.

The final plenary session was devoted to review presentations by the chairs of the four technical working sessions. Each chairperson reviewed the activities of his or her respective group, and presented comments and recommendations made by the experts. Synopses of each of these presentations are given in the remainder of this section to complete the executive summary of the activities of the Workshop on Indoor Air Quality Research Needs.

Dr. Nathaniel F. Barr, Department of Energy:

Studies on risk analysis of exposure to indoor radon and radon progency concentrations, were reviewed. The panel and the audience identified and extensively discussed several potential problems to be recognized. These were:

1. There would be a very wide range of uncertainty associated with health risk estimation derived from current data base.
2. The use of results of health risk analysis for purposes other than R&D planning (i.e., policy formulation, regulation and public information) should be approached with extreme caution.
3. The scope of health risk analysis should be broad enough to provide perspective on factors such as the health implications of inadequate housing and other safety features of the indoor environment.
4. It is suggested that results of ongoing risk analysis be provided to participants in advance of future research and development workshops and discussions of these scheduled early in the agenda.

The need for a systematic approach to risk analysis studies specifically addressing indoor environments was also established.

Dr. Lance Wallace, U.S. Environmental Protection Agency

The monitoring section was divided into six groups. Each group considered not only research needs in monitoring but also paid explicit attention to the availability and adequacy of the instrumentation needed to perform the monitoring.

Central Themes

In the final plenary meeting of the monitoring session, the combined groups identified four unifying themes:

1. The total exposure concept. A person's health can be affected by indoor, outdoor, and in-vehicle exposure. The total exposure concept (i.e., 24-hour exposure) must be an integral part of all monitoring efforts if only to determine the relative contribution of the indoor air to that exposure. Another important consideration is the multimedia effects of water and food and the correlation of these data with body burden data (e.g., breath, blood, and urine levels).

2. Coordination. The complexity of the indoor air quality problem requires interagency cooperation; cooperation among health, monitoring and instrumentation people; and interactions with industry, architects, builders and engineers, academia, and Government.

3. Careful planning of field monitoring. Many examples exist of inadequately planned field studies that neglected to record the one item of information that later was found to be necessary. Thus, there is a need to design monitoring studies that make precise statements about the objectives, protocols, data requirements, and interrelationships with other efforts planned or in progress in the public and private sector.

4. The "sick building" concept. Many panel members felt that there is a new and very real problem emerging in indoor air studies: buildings, including very large areas, in which considerable proportions of their inhabitants are affected adversely. Such buildings associated with outbreaks of disease or complaints present an opportunity to study a condition that affords a high probability of source identification, provided a thorough study can be launched.

Group-Specific Comments

Organics, Odors, Nitrosamines, Pesticides and PCBs

Volatile Organics

For broad-spectrum sampling, the present method of choice employs solid-adsorbent collectors such as Tenax-GC followed by thermal desorption and gas chromatography/mass spectrometry (GC/MS) identification and quantification. More work is needed on this method, however, including the exploration of metal versus glass collectors, break-through volumes, preparation, artifact formation, and standards for quantification. (Standards exist for only 40 of hundreds of volatile organic chemicals.) Retention and collection efficiencies also need improvement. Studies to improve and standardize the performance of this method are strongly recommended. Intercomparison of results is presently impossible in the absence of a standardized method.

Once the method is improved, a phase two effort is desirable to study problem buildings, ventilation rates, occupant complaints, organics, and pollution sources.

An additional monitoring study of organic emissions from building materials is recommended. This would involve head space analysis and examination of ventilation rates, temperature and humidity effects, which may provide some control over these emissions.

Three other monitoring recommendations are for studies of: wood-burning stoves, fireplaces, kerosene space heaters, and unvented heaters; auto interiors, particularly new auto plasticizers, in conjunction with ventilation rates; and correlations of breath and blood levels with indoor or personal exposures. For this last item, more knowledge is needed on absorption, metabolic pathways and exposure/dose relationships for numerous organic compounds.

The final research recommendation of the organics subgroup is for a study of mutagens derived from cooking. Protein pyrolysis produces potent mutagens, some of which volatilize in the air. One study indicates that 90 percent of the basic fraction of mutagens from cooking escape to the air in the kitchen. In such a situation, the inhalation dose may be comparable with that due to ingestion. A second study concluded that female kitchen helpers suffer about three times the cancer risk of the general population.

Pesticides and PCBs

The principal instrumentation, which is to collect pesticides and PCBs on polyurethane foam (PUF) followed by solvent elution and GC/MS, appears to be adequate. Ethylene glycol has been used as a collection medium but has limitations. The polyurethane foam is sometimes backed by Tenax GC to collect a wider range of organic compounds, and has also been fronted with a filter that can then be tested for metals and total particulate mass.

The basic need is for an automation method that will increase the throughput of the analysis. Large numbers of samples will be required to characterize homes and give a frequency distribution of exposure.

Second, organic particulate matter must be characterized in addition to organic vapors. No adequate technology now exists, however, for collecting sufficient volumes of indoor air using personal or portable samplers to extract and analyze the organics in aerosols and on particulates. The critical need is for the development of small, powerful, and quiet samplers and an extremely sensitive analytical protocol for extracting and analyzing organics from a very small mass of collected particulates. Organics that are partitioned between aerosols and vapor (such as PCBs and possibly plasticizers from auto interiors) also need special methods.

A third requirement is for analytical methods for synthetic pyrethrins and carbamates, both compounds of increasing importance in the pesticides area.

The final research recommendation of instrumentation need by the pesticides and PCBs subgroup is for a more compact medium flow personal pump for semi-volatile collection on PUF. It is anticipated that instrument manufacturers will produce this pump within the next year.

Other research needs for pesticides include the following:

- Coordinate with the nationwide pesticide usage survey undertaken by the EPA Office of Pesticides and Toxic Substances. Adding monitoring to that effort would provide extremely valuable data.
- Monitor for PCBs, a major source of which is probably burned out ballast from fluorescent light fixtures.
- Monitor for pentachlorophenol (PCP), particularly in log cabins.
- Coordinate with body burden studies.

Nitrosamines and Odors

Several major indoor sources of nitrosamines are gas stoves, rubber products, tobacco smoke, and diesel oils and auto coolants. The instrumentation for nitrosamines appears to be adequate for laboratory studies only, and includes GC/MS analysis and the TEA analyzer developed specifically for nitrosamines. While the latter instrument looks promising, it requires further validation.

Recommended monitoring studies should examine nitrosamine concentrations with respect to the following variables: gas versus electric cooking, vented versus unvented hoods, the effect of tobacco smoking on indoor concentrations, gasoline versus diesel fuel in autos and buses, and the effectiveness of charcoal filters in reducing nitrosamine concentrations (a control research need).

A related compound of increasing interest is hydrazine, a possible product of reactions involving bleaches and washing materials. Instrumentation is inadequate at present for personal or indoor monitoring, and needs to be developed. Once developed, a small monitoring program to learn the extent of the problem would be a desirable first step.

This subgroup also urges the investigation of the increasing number of complaints about odors. A potentially large economic impact may be involved, particularly with air and carpet fresheners, which may anesthetize the olfactory sense or mask the smell until normal ventilation reduces the concentration of the odor. Present "instrumentation" (i.e., panels of persons ranking the odors under investigation) is the only proven method of quantifying odor levels. A more specific approach would be to link specific chemicals with certain odors and develop instrumentation accordingly. The impact of outside odors on indoor air should be examined.

Aerosols and Asbestos

The instrumentation is inadequate for aerosols and asbestos. A personal monitor is needed for RSP that is capable of collecting sufficient material over 8-hour periods to allow chemical analysis. One such system is now under development at the National Bureau of Standards.

Also required is a personal monitor that gives an instantaneous readout of mass. (The Piezobalance and GCA's Respirable Aerosol Monitor give instantaneous or near-instantaneous readout but are too bulky for a person to carry easily.) In addition, the monitor should have the capability for data logging, an electronic memory, a clock, and a code to indicate the activity of the person at the time the exposure is occurring. These features will allow identification of activities associated with increased exposures.

For monitoring, the parameters to be measured are size and mass, chemical composition, time resolution, and activity patterns of the population. The highest-priority monitoring effort is a total exposure monitoring study to measure indoor, outdoor, and in-transit exposures as the three major components. An ideal study would provide a frequency distribution of exposures in one urban area and then use existing time budget studies to extrapolate to exposures in other areas.

Secondly, controlled or chamber experiments for such sources as tobacco smoke, cooking, vacuum cleaning, diesel particulates, and wood burning should be carried out. These would include studies in growth, decay deposition, and transport.

A third priority is for site-specific studies on office buildings, residences, autos, and subway platforms.

For asbestos, the instrumentation is not adequate for airborne analysis. We need continuous instrumentation and continuous fiber counts with size, determination, and identification of the fibers.

Criteria Pollutants

The subgroup strongly recommended the evaluation and calibration of all present monitoring instruments for indoor use. Instruments have been tested by NIOSH at occupational concentrations, but they have not been evaluated and validated at expected nonoccupational indoor levels (which may be 100 times lower than occupational levels) and are not usable, except by trained personnel.

Carbon monoxide is the only pollutant for which instrumentation appears adequate and for which a large scale study could be undertaken now. Highly recommended studies include gas heating, cooking, transportation sources and 24-hour exposure studies. (EPA presently plans a large-scale urban study for next year.)

For NO_2, the instrumentation is satisfactory for long-term (days to weeks) integrated analysis. (The Palmes diffusion tube and the modified West permeable-membrane badge have both been validated recently by the NBS.) However, neither method is adequate for short-term monitoring. A short-term standard for NO_2 soon may be issued. The standard is not expected to apply to indoor levels, and short-term monitoring requirements may not be necessary unless the NO_2 health effects deviate from the linear dose hypothesis. Portable instrumentation that will measure ambient levels may be needed for other uses.

Another recommendation is a chamber study that would involve a single, specially-designed house to study combustion and appliance emissions of NO_2. Concentration should be examined as a function of source strength and air exchange rates, with and without exhaust hood operation.

Statistics and Modeling

A fourth group focused on statistics and modeling. Collectively, the group agreed that environmental monitoring programs are sufficiently diverse as to require unique sampling strategies. One possible solution to this dilemma is the NIOSH Sampling Strategy Manual. In general, a potential strategy should consider average versus peak exposures, time histories, short- and long-term effects, and the relation of individual exposures to individual responses. Again, quality control and quality assurance were mentioned as pressing needs for all exposure and monitoring studies.

Exposure models are needed. Fugas and Ott have worked on determining exposure as the product of pollutant concentration in a particular microenvironment and the time people spend in each microenvironment. The difficult job of defining microenvironments has only recently begun, and therefore no agreement exists as to the number to be studied. (The number obviously depends on how finely they are subdivided.) However, if a reasonable number of microenvironments can be identified and monitored to determine the exposure range in each microenvironment and if the time that people spend there can be determined from national time-budget studies, then the exposure of large populations can be estimated. Nevertheless, individual exposure studies are still needed for epidemiologic research.

The subgroup feels that a long-term study in economic analysis components should be added to the activity pattern/sociologic type of modeling that is being performed.

Radon

Substantial research efforts are needed in four areas. Studies of indoor radon and radon progeny concentrations should be undertaken to understand their dynamic behavior in buildings and to determine the range and distribution of radon and/or its progeny in the nation's building stock. Before proceeding with a large-scale survey it is necessary to evaluate the usefulness of various passive techniques for characterizing the concentrations of radon and/or radon progeny in residences, and to assess the viability of short-term measurements to represent annual averages. Finally, it is necessary to characterize radon sources and ground transport in order to provide predictive capabilities for indoor concentrations of radon/radon progeny.

Formaldehyde

The formaldehyde subgroup determined that the sampling methods are inadequate in two areas. One is population exposure: the detection limit is only 200 ppb, an inadequate level of sensitivity for long-term, low-level exposures. A desirable level would be 20 ppb.

The second area of instrument inadequacy is in source assessment. In this case, continuous monitoring is needed with a 30 ppb limit of detection. The subgroup recommended a monitoring program (dependent on improving the instrumentation) that would examine correlations between formaldehyde levels in the air, sources, and ventilation effects.

Dr. Laurence J. Doemeny, National Institute for Occupational Safety and Health:

The Instrumentation Group recommends that trade associations, the Small Business Administration, and educational and research institutions such as EPRI and GRI actively participate in research and in information dissemination on indoor air quality.

We know legionnaires disease is a real threat. We know formaldehyde has driven people from their homes; we know students in academic laboratories have been overcome by chemical vapors, and we know that excessive levels of various pesticides, polychlorinated biphenols, and other pollutants may occur in the indoor environment. The panel and the participants feel that published materials and the indoor air quality research plan should focus on the issues and use appropriate language to stress the problems where they exist.

We note that the list of sources of pollutants should include important areas such as landfills, water that is a source of radon, and chemical dumps.

Quality Assurance

Quality assurance greatly concerned the instrumentation group. Recent Supreme Court decisions have highlighted the need for good data. Attention to quality assurance efforts may be an integral part of any national program in indoor air quality. The group fully embraces the concept of quality assurance described by J.S. Hunter in a recent *Science*, (210: No. 4472, pp. 869, 1980) article titled "The National System for Scientific Measurement." This is a sound and reasonable approach to quality assurance for methods development and instrumentation.

The new instruments needed for indoor monitoring also serve other ends, such as ambient air monitoring, occupational exposure, and hospital monitoring. Incentives will be required, however, if private enterprise is to undertake significant efforts in instrument development. For industry to invest in this research, instrument manufacturers must be convinced that indoor air problems do exist and that regulations or guidelines will be issued in an effort to eliminate these problems.

Technology transfer is another key element of an indoor air quality program. Physicians should be trained to understand symptoms relating to poor indoor air quality and instructional materials should be upgraded. This point applies as well to the other technical areas addressed by the Workshop.

The group then broke into four smaller subgroups: aerosols, radon, inorganics, and organics. The topic of biological agent sampling approaches was not covered due to the absence of experts at the Workshop.

Aerosols

Aerosol calibration methodology is available for laboratory purposes. No simple techniques exist, however, for field calibration except secondary methods to check the operational performance of real-time monitors. Most aerosol monitors require active sampling from the surrounding environment and exhibit some degree of particle size discrimination or bias. The use of so-called total suspended particulate (TSP) samplers or monitors is discouraged. Specific and well controlled particle size limitations (such as by the use of size preselectors and/or properly designed inlet configurations) should be required to prevent errors in inconsistencies associated with open-endedness at the large particle end.

Accurate instruments and techniques often are difficult to find because of the inherent inaccuracy and ambiguity in most of the reference methods. In general, however, intermethod comparisons usually yield agreements within a factor of two.

Repeatability, using a given device under similar monitoring conditions, is frequently within 10 to 20 percent and occasionally much better.

Radon

For radiation, much of the development work in the last 20 years has responded to problems of uranium mine exposures, releases from uranium tailings, high indoor exposures, and structures built on reclaimed phosphate lands.

Adequate, if not optimal, techniques exist and are being applied in research studies of radon and radon progeny concentrations in indoor air. These studies are dependent on ventilation rate, heating and cooling system operating parameters, meteorological variables, living habits, particulate size distributions, trace degree, and the degree of attachment. Improvements are being made, however, in many of these techniques to make larger-scale field studies more practical.

Passive integrators of radon gas exposure over periods of weeks or months have recently been developed and are being evaluated. They are likely to be adequate for large-scale surveys. There is a strong need for analogous integrators for radon progeny exposures.

Many of the techniques suitable for measurement of radon 222 can be applied to radon 220.

Few data exist on exposure to thoron and on thoron's contribution to radon readings. More effort is required to adequately define the measurement techniques and protocols for general use, to provide standard calibration facilities and sources, and to perform detailed evaluations of various instruments and measurement methodologies.

Inorganics

The inorganic subgroup confined its discussion to carbon dioxide, oxides of nitrogen, carbon monoxide, and hydrazine.

Area monitors measure carbon monoxide at 1 ppm, carbon dioxide at 10 ppm, and NO at 5 ppb. Area monitors are needed to measure nitrogen dioxide at the 0.01 ppm level.

Personal integrating monitors may lack specificity indoors, but are available for NO_2 at the 20 ppb level for 2-day samples.

Personal monitors are required for hydrazine at the 5- to 50-ppb level and for carbon monoxide at the 1- to 5-ppm level.

None of the above methods has been validated, recognized, or had quality assurance practices applied for indoor air measurement. Alarms to alert residents to unsafe levels of CO and CO_2 are needed, as are low-cost miniaturized instruments.

Organics

The organics session devoted its time to nitrosamines and polynuclear aeromatics (PNA). Although the nitrosamine methods may not have been validated, suitable nitrosamine sampling and analytical methods are available.

Personal and area sampling/analytical methods may be available for PCBs, fluorodane, and organic solvents. Methods for PNAs and formaldehyde are either feasible or available.

For control instruments, research is needed to determine if existing room sensors such as ionization smoke sensors can be adapted to indoor air quality measurements. Ultrasonic, infrared, solid-state lasers should be considered for control monitors. Control strategies to monitor the interplay between the ambient levels and filter loading situations will be required.

Protocols do exist for measuring air exchange and filtration rates. This is the ASTM method E-741. Inexpensive methodologies for measuring infiltrarates are, however, needed.

For general instrumentation, we need miniature mass spectrometers and infrared analyzers. Pumps may need to be redesigned or reconfigured for the different sampling strategies that monitoring may employ. Basic research is needed to further understanding of solid sorbants, and to define the catalytic effects of the sorbent on the low-level samples.

Dr. Lance Wallace made a statement regarding time and motion studies where subjects push a button to register their locations. This topic has been discussed by some of the staff at the National Institute for Occupational Safety and Health. Technology is available to place position monitors on persons in the workplace setting, although we must not ignore the difficulties involved in using this type of monitoring.

Dr. Robert Goyer, National Institute of Environmental Health Sciences:

The respiratory system is the most vulnerable to indoor air pollutants. The most neglected is the nervous system, particularly in behavioral effects.

No known causes have been determined for many chronic diseases in society. The role of the indoor environment should be considered in relation to these diseases, either as augmentation factors or as primary etiological factors.

The indoor environment offers an opportunity to study the effects of a number of potentially harmful substances on a cross section of the population, which includes the aged, the invalid, the chronically ill, pregnant women, and infants.

All efforts to study health effects are dependent on the availability of instruments and techniques for monitoring. For health studies, two kinds of instruments are needed: an instrument to record peak short-term exposures and long-term integrating instruments.

The Health Effects Group clustered pollutant problems into seven classes of substances. These were: formaldehyde, radon, combustion products, biologicals, organic compounds, particulates, and tobacco smoke.

Formaldehyde

Rates of formaldehyde emissions and factors affecting the rates of emission from various structural products should be characterized. We need toxicological research concerning the carcinogenic effects of low levels of formaldehyde.

Also needed are toxicologic studies of the mechanisms of low-level acute effects relating to sensitization and immune mechanisms. Epidemiologic studies on the alleged health effects in the indoor levels must be studied. These studies should include buildings where consumer products, furniture, and wallboard emit formaldehyde.

Radon

Our group thought that the first priority in monitoring is to obtain a national assessment of radon levels in personal dwellings. Once a national assessment has been made, we could then identify regions or populations where epidemiologic studies of low-level effects could be profitably performed. Health studies should include miners who have been exposed to low levels of radon where control measures are already in effect.

Combustion Products

A third topic in the Health Effects Group was combustion products. Most homes today use multiple sources of fuel. Some of these fuel sources, such as wood, have not been used extensively in recent years. The combustion products of greatest concern are carbon monoxide, nitrogen oxide, nitrogen dioxide, and aromatic hydrocarbons.

The measuring of carbon monoxide and nitrogen dioxide should be correlated with carboxy and met-hemoglobin measurements. A number of particulates and organics may act synergistically with other indoor pollutants and produce adverse effects. These interactions should be studied.

In addition, epidemiologic studies of people exposed to combustion products should be correlated with emissions from other sources.

Biological Pollutants

The Health Effects Group considered biological pollutants a high priority research need. Two aspects must be considered:

1. The allergenic properties of biologics

2. Biologic substances as infectious agents.

Common allergens found in the home include fungal spores, pollen, mite dust and microbial products. The indoor environment may provide ideal conditions for growth of fungi. An example is aspergilla, which may be an allergen and may produce an infectious disorder, or aspergillosis.

Continued exposure to allergens may cause a hypersensitivity syndrome. Subdivisions of this syndrome are hypersensitivity pneumonitis and/or humidifier fever. Both of these are thought to be due to fungal or protozoan contamination of the ventilation system or humidification apparatus. This deserves more study.

Cats, dogs, birds and other pets in the home may also be sources of allergens that cause either asthma or hypersensitivity pneumonitis.

Many common infectious agents may be airborne. As buildings are sealed more tightly, the risk for airborne infections increases proportionately. Therefore, incidents of infectious diseases must be correlated with levels of air exchanges in buildings. Occasionally, organisms are isolated in sealed buildings, allowing such correlations to be made.

Organic Pollutants

The Health Effects Group also made recommendations on organic pollutants which, with the exception of formaldehyde, were assigned lesser priority. Nevertheless, many organic substances require further toxicologic and monitoring study. We have little information about their presence in the indoor environment.

The organics were broken into three groups: pesticides, controlled organics, and indoor particulates. Controlled organics were defined as consumer products that are brought into a house by its occupants. Therefore, the emissions from controlled organic pollutants could be controlled.

Uncontrolled organics are substances emitted from furniture, household articles, or from the structure of the house.

Some organics are considered potential health problems for a variety of reasons. These include 1,4-dichlorobenzene, nitrosamines, and pentachlorophenol and other related chlorinated hydrocarbons. The latter should be studied because of their dioxin content. Dioxin should be monitored.

We need more complete tabulation and recording of the toxicologic information on these classes of organics. The National Toxicology Program studies the toxicologic effects of chemicals, and the Consumer Product Safety Commission has compiled a list of ingredients contained in most consumer products.

For controlled organic emissions, there is a need for product emission data and for appropriate labeling to prevent misuse. This is being done for pesticides. A central repository of toxicologic data should be provided for consumer products.

Dr. Janet C. Haartz, National Institute for Occupational Safety and Health:

Before I summarize the discussion of the Control Technology group, I would like to acknowledge and thank the panel members that worked with me: Dr. Amos Turk, Dr. James Woods, Mr. Gary Roseme, Mr. Bill Mirick and my cochairman, Mr. Robert Hartley. I'd also like to thank the participants, who contributed significantly to the development of our recommedations.

Most of the participants in the control technology session felt that our state of knowledge about indoor air quality is extremely rudimentary. Although there are data relating to hazardous industrial workplace environments, little is known about hazardous pollutants in commercial and residential environments. The view was widely expressed that adequate controls will be developed and implemented only after we determine, qualitatively and quantitatively, the characteristic pollutants present in all types of indoor environments. Those pollutants which cause adverse health effects need to be identified so that controls which are appropriate are developed. The group did feel, however, that there is sufficient potential for hazardous conditions in indoor spaces--made worse by pollutant build-ups associated with some energy conservation techniques--that we cannot delay control technology research until all of the problems are delineated.

In our discussions we periodically returned to the need for various types of information or sets of data. Therefore, although these concerns have been enumerated by the three previous speakers, those most directly related to control technology research need to be reiterated. They include:

1. Standard methods for identifying and quantitating emissions from materials

    - In developing these methods, one must be cognizant of variables such as temperature and actual use of the materials, and thence include these variables in the standard methods.

2. A systematic characterization of indoor spaces

    - The data could be used to develop models for air and contaminant movement within indoor spaces with which the effectiveness of control strategies could be determined.

3. Standard methods for evaluating air cleaning equipment

    - These methods would allow the determination of efficacy in removing vapors or particles under real conditions and not only under very constrained laboratory situations. The use of standard methods would also allow comparison of data from different laboratories or tests.

The discussion of and recommendations for control technology research strategies were divided into four categories: ventilation, source removal or exclusion, contaminant removal, and product substitution.

Consideration of the last category, product substitution, was unproductive in terms of developing research needs. Too little information is available on hazardous materials to adequately define research leading to substitutes. In the three remaining categories, we developed and suggest priorities for 20 or more research recommendations in each. Details of these recommended actions are in the panel report. A summary follows:

Ventilation--We include in this category, infiltration in addition to mechanical and passive/natural ventilation. A prerequisite for control technology research is an inventory of contaminants. We need to determine sources and generation rates, and reexamine the current prescriptive ventilation rates, such as those recommended by ASHRAE, to ascertain if they provide adequate levels of contaminant control. Although NIOSH has done some research on ventilation as a control for industrial workplaces, other indoor environments are not covered in the NIOSH data. The technology developed for industrial environments needs to be evaluated for possible transfer to use in commercial and residential environments.

Techniques for use of air-to-air heat exchangers must be evaluated and the need for these, in addition to or in place of other ventilation systems, must be determined.

An inexpensive means of measuring the actual ventilation rate experienced by a building over a period of time--not merely the mechanical or forced ventilation rate, but the actual ventilation rate--is needed.

We also need to determine the concentration of pollutants as a function of ventilation rate in a statistically significant number of indoor spaces. This determination should cover not only residences, but all of the categories of buildings included in the research plan.

Source Removal and Exclusion--This category includes techniques for actually removing the source of a pollutant or for excluding the pollutant by, for example, sealing off the source. A prerequisite for development of source removal/exclusion technology is identification of the sources of emissions. For example, we need to determine the emissions from constructio materials, from equipment and from other sources in the same way that the Consumer Product Safety Commission has identified and listed emissions from various specialty chemical products. Emissions must also be examined as a function of process. For example, what is expected from cooking or from operating a copy machine?

Emission rates and their dependence on ambient conditions are also important. For example, the rate of emission of formaldehyde from insulatio materials has been shown to be somewhat dependent on humidity. It is reasonable to assume that other pollutants also have a similar emission rate dependence on ambient conditions. In order to develop effective control technology strategies, we also need to develop an inventory of emission rates by category.

An effective control strategy is the use of coatings and encapsulating compounds that can retard or eliminate pollutant emission. However, a comprehensive listing of these materials is needed as a basis for identifying and evaluating additional applications for them.

Another important research need is to develop construction technologies or techniques that will exclude pollutants. A corollary is to develop remedial techniques which will exclude radon, pesticides, and other pollutants. Although some research in this area has been initiated by DOE and HUD, much remains to be done as there are no proven techniques in widespread use.

Contaminant Removal--Included in this category are the control strategies which remove the pollutants as they are formed, without removing or excluding the sources thereof. The control technology panel felt that there is a real potential for implementing technology transfer in this area. There is a vast amount of knowledge on air cleaning mechanisms or equipment that is used by industry and the military which could be adapted for use in other indoor spaces. An end-of-service-life indicator for air cleaners was considered an important research need. This mechanism would indicate either visually or audibly that a buildup of pollutants had occurred and the device was no longer effective. Finally, one research need in this category which relates only to residential environments: the development of energy-efficient range hoods or similar devices which are not only effective for removal of air, but also are effective for actual contaminant removal via use of charcoal or other types of filters that are easily used and maintained.

In closing, I would like to reiterate that the above is only a summary of our discussions. A detailed compilation of the research needs developed by the control technology group is included later in the text.

The remaining topics on the agenda consist of followup activities and a general discussion.

Mr. David Berg, Workshop Cochair, EPA:

Followup Activities:

Each panel will compile a written report. The Workshop report will be distributed to all workshop participants.

The revised Research Plan, which will be based in part on the Workshop report, will identify the research needs in indoor air quality. Before the Plan becomes final, the Interagency Research Group will submit the Plan for approval by policy level people in each participating agency. The research agenda, when completed in draft form on the basis of suggestions made at this meeting, will be used by the Interagency Research Group and its subgroups to design an overall Federal research program.

We are also asking workshop participants to assist in updating the inventory of current and ongoing research projects in indoor air quality. Research now underway must relate closely to future work. Thus, through this tool, we can improve the overall quality of indoor air research.

Meanwhile, the Office of Management and Budget has been made aware that the Interagency Research Group exists. OMB has consented to the IRG's continuation as an ad hoc organization.

The Clean Air Act will be reviewed by the Congress in the coming legislative year. Various committees and subcommittees have indicated that they may hold hearings on indoor air quality. These would be the first comprehensive hearings on indoor pollutants extending in scope beyond the workplace environment.

Section 1.0

INTRODUCTION

The Interagency Research Group (IRG) on Indoor Air Quality is a continuously functioning body established to bring together Federal Agencies concerned with research on the indoor environment. Agencies actively participating include the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), U.S. Department of Housing and Urban Development (HUD), Consumer Product Safety Commission (CPSC), Centers for Disease Control (CDC), the National Institute for Occupational Safety and Health (NIOSH), the National Institute of Environmental Health Sciences (NIEHS), Occupational Safety and Health Administration (OSHA), National Bureau of Standards (NBS), U.S. Department of Defense (DOD), Coast Guard, Bureau of Mines, and National Science Foundation.

The IRG has undertaken to: (1) prepare an inventory of ongoing and recently completed research on indoor air quality; (2) draft a research strategy; (3) develop a preliminary research agenda; and (4) organize a workshop to broaden the technical base for information on items (1), (2), and (3). To facilitate meeting these responsibilities, the IRG established five working groups of Federal experts in the following technical areas: (1) monitoring and characterization; (2) instrumentation; (3) health effects; (4) controls; and (5) risk analysis. Each group has the ongoing responsibility of assisting the IRG in the appropriate area.

A smaller interagency Workshop Steering Group (WSG), consisting of representatives from EPA, DOE, HUD, CPSC, and NIOSH, organized a national Workshop on Indoor Air Quality Research Needs to solicit expert review and public comment on: (1) the draft strategy plan and (2) indoor air quality research needs and objectives. Preparatory materials on these two items and other relevant information generated by the WSG and the working groups (including a sixth group, on Radon and Radon Progeny) were compiled in a briefing book. The sixth group was established specifically for the workshop to examine for one class of pollutants information contributed by all of the technical areas.

The Workshop on Indoor Air Quality Research Needs was held in Leesburg, Virginia, on December 3-5, 1980. Specific objectives included:

- Completing a state-of-the-art review of knowledge on indoor air quality
- Completing the inventory of recent and ongoing research (Federal and non-Federal) related to indoor air quality
- Defining the research agenda necessary to obtain a sufficient understanding of indoor air quality pollutants, sources, measurement methods and instruments, controls, and risks

A multidisciplinary group of nearly 200 U.S. and Canadian technical, scientific, and policy experts representing the Federal, public, and private sectors* was assembled. All participants had current or recent experience in research, research management, or manufacturing items associated with indoor air quality.

The workshop comprised an orderly sequence of specialty working and plenary sessions. Specialty working sessions were led by panels whose members, selected before the workshop, were recognized experts in the five technical areas of the working groups: monitoring; instrumentation; health effects; controls; and risk analysis. A sixth specialty group, on radon and radon progeny, was also led by a panel of experts and represented a case study that incorporated all subjects addressed in the other five specialty sessions. The plenary sessions were led by representatives from EPA and DOE, the cochairs of the IRG on Indoor Air Quality. Sessions were conducted as follows:

1. Opening Plenary Session - to formally convene the workshop, explain its organization, and reiterate its purpose and objectives (morning of December 3).
2. Technical Sessions - concurrent sessions in each of four central technical areas (monitoring, instrumentation, health effects, and controls) under panel leadership to review the state of the art, discuss research strategies, and identify research needs (afternoon of December 3, morning and afternoon of December 4).
3. Technical Session in Plenary - to present and discuss issues of the special topic of radon and radon progeny (evening of December 3).
4. Technical Session in Plenary - to present and discuss issues in the technical area of risk analysis (evening of December 4).
5. Closing Plenary Session - to allow the panel chairs to report findings to all participants for discussion and then adjourn the proceedings.

During the workshop, many ad hoc and executive meetings spurred further discussion and fostered exchange of information among the working sessions.

The workshop report will contribute to four clearly defined products necessary for developing a national program in indoor air quality:

- State-of-the-Art Review
- Inventory of Related Ongoing Research

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* A complete list of all participants is contained in Appendix A.

- Inventory of Research Needs
- Unified Research Strategy

This document summarizes the conduct of the workshop and presents the findings and recommendations that were developed. The first section presents the Executive Summary; the second contains a synopsis of presentations given during the plenary sessions on the mornings of December 3 and 5; and the third provides technical reports generated by the panels of each specialty working session and a summary report on risk analysis. Appendix A contains a complete list of all workshop participants and the technical sessions to which each contributed. The inventory of research is being published separately.

Section 2.0

December 5, 1980/Morning Plenary Session

Synopses of the workshop keynote presentation by Dr. Kurt Riegel and introductory remarks by Mr. David Berg, the workshop cochair, are found in this section.

Synopses of the presentations on Policy Aspects given by Mr. Dwain Winters (EPA), Mr. Howard Ross (DOE), Dr. Irwin Billick (HUD), and Dr. Peter Preuss (CPSC) are also included in this section.

Dr. Kurt Riegel, U.S. Environmental Protection Agency:

Welcome! We worked hard to identify people who could bring a high level of expertise to this meeting. We publicly announced it in hopes of drawing additional knowledgeable persons. The attendance list contains an exceptional collection of people who are well acquainted with many aspects of indoor air quality and, in some cases, the remedies.

The Federal Government's interest in indoor air quality extends back at least 5 years and perhaps as many as 30 years. Recent events have added to the sense of urgency that several Federal Agencies attach to the exposure to indoor air pollutants. But, we have discovered a lack of coordination between the Federal Agencies in pursuing their individual research and development responsibilities.

Thus, we formed the Interagency Research Group on Indoor Air Quality, which has several purposes. The group first sought to acquaint the Federal establishment with research and development related to indoor air quality in each Federal Agency. Second, the group made a concerted attempt to coordinate the activities of each Agency toward common objectives and clearly stated goals.

This meeting is an important milestone toward coordinating a Federal research and development program on indoor air pollution.

A number of changes are taking place on the Washington scene, which will affect the way Federal Agencies address indoor air pollution. The idea of trying to adopt traditional regulatory approaches to problems of exposures to indoor air pollutants is scary--nonregulatory approaches, particularly in the indoor case, are likely to be more appropriate to the subject, as well as to our times. We hope that Federal activitites will address indoor air quality in a way that is practical and not burdensome to the public.

A number of recent events have affected EPA's outlook on indoor air pollution. For example, EPA now believes that worrying only about the outdoor ambient environment is less than completely desirable, since most people spend most of their time indoors. Outdoor criteria alone do not protect a person's health in a total exposure sense. This concept of total exposure to pollutants is gaining wider and wider currency in the Federal Government. Total exposure, or the total burden to which we are exposed, includes the indoor environment. Research findings for the indoors may greatly affect outdoor ambient air quality standards.

The interactive indoor/outdoor effect needs to be more widely considered. We have made some progress in our knowledge about some of the consequences of pollutants found indoors. For example, we know much about radon. However, the state of knowledge for other indoor pollutants is less complete. Before Government Agencies even consider action to address health effects of indoor exposures, we must determine which indoor pollutants exist, at what levels.

Instrumental techniques must be developed for measuring pollutants in practical ways. How do those levels affect human beings? What is the total risk to a human being? What controls are available? What actions ought Federal Agencies to take to help protect human health? That is the general background of our concerns. We hope this meeting will sharpen the Federal research and development plan for indoor air pollution over the next 5 to 10 years.

Mr. David Berg, U.S. Environmental Protection Agency:

Over the next few minutes, I will cover two topics:

1. The overview of the draft Research Plan for indoor air quality
2. A review of the purpose and structure of this meeting

Overview of the Draft Research Plan for Indoor Air Quality

The emerging consensus that indoor air quality may be a national health concern is a stimulus for having this meeting. Limited data suggest that indoor exposures to several pollutants--including NO_x, particulates, asbestos, radon and formaldehyde--comprise a significant fraction of total exposure. The concern for energy conservation increases the potential for adverse exposures to pollutants as air exchange rates are reduced and new sources are introduced to the indoor environment. Several Agencies have responded to this feeling. These responses include the advent of the Interagency Research Group on Indoor Air Quality.

Members of the Interagency Research Group come from several Agencies. Environmental Protection Agency (EPA) and the Department of Energy (DOE) are the cochairs. The Department of Housing and Urban Development (HUD), Consumer Product Safety Commission (CPSC), Department of Health and Human Services (DHHS), Centers for Disease Control (CDC), the National Institute for Occupational Safety and Health (NIOSH), and the National Institute for Environmental Health Sciences (NIEHS) are also members. Participating groups include the General Services Administration (GSA), Department of Defense (DOD), and the National Bureau of Standards (NBS).

In summary, the purpose of the Interagency Research Group is to coordinate Federal efforts to understand and deal with problems of indoor air quality. Five working groups were established by the Interagency Research Group to facilitate this process. These are monitoring, instrumentation, health effects, controls, and risk analysis. In addition, the draft plan suggests that there would be two other groups established--one on data handling and information and another on quality assurance.

The Interagency Research Group has prepared a draft Plan to document the working group structure, to detail the roles of the working groups, and to suggest the broad research elements for each group. The Plan seeks to establish a mechanism to coordinate federally sponsored research and to use the research results to address the cleanup and prevention of potential threats to public health. Thus, Federal efforts can be streamlined, made more cost effective, and can avoid unnecessary duplication.

The Plan proposes several functions by the working groups. These functions are:

- To perform a state-of-the-art review of knowledge on various aspects of the indoor air quality problem
- To review and update the draft Research Plan
- To review and correct the inventory of research projects in indoor air quality that are underway or were recently completed
- To develop a research agenda to guide the selection of projects by several Agencies that will fund research and to guide private and nongovernmental groups that may conduct research
- To coordinate the research activities of the several Agencies
- To conduct periodic technical reviews.

I stress that the research called for by the workshop and the Interagency Research Group will not provide the basis for another major Federal intrusion into private lives. Rather, the Plan identifies the needs of several organizations for reliable information on which to base their decisions that will affect the public health. The need for information on indoor air quality is also shared by individual architects, builders, and building owners.

Purpose and Structure of the Workshop

This workshop has a number of purposes:

- To define clearly the specific research efforts needed to assemble a research program to understand and mitigate the indoor air problem
- To summarize the indoor quality problem, based on implementation available to the experts present at the workshop .

- To receive workshop comments on the draft Research Plan
- To correct the inventory of indoor air research and programs.

The workshop is structured around five technical areas: instrumentation, controls, monitoring, health effects, and risk analysis. A cross-cutting session will look at one pollutant, radon. An expert panel for each technical session will prepare a summary report on the information gathered. Each report will contain eight separate sections:

1. An abstract
2. A summary of the session
3. Comments on the draft Research Plan
4. A review of the state of the art
5. The preparatory documents from the technical working groups
6. A list of major areas of omission in the draft Research Plan
7. The descriptions of individual research needs
8. A commentary on specific recommendations.

The workshop report will have several uses. The Interagency Research Group will use this document to help prepare an integrated Federal research program. The document, which will represent the sum of thinking among the most qualified experts, will be made available to the technical community and to others who are interested in the problems and mitigation techniques for indoor air pollution.

Mr. Dwain Winters, U.S. Environmental Protection Agency:

Introduction to this Session:

The panel members assembled for this session have not been asked to speak as representatives of their respective Agencies. Instead we have asked them to serve as a panel of experts who will speak of their personal perceptions of the problems of indoor air quality, and their Agency's involvement with this problem.

Indoor Air Quality Research Needs from Two Vantage Points

Indoor air quality is an emerging issue which is still in the early stages of problem identification. As a consequence, Federal Agencies have not formed firm policy decisions, nor have they clearly identified all of the issues that are involved. One job of the research community is to provide the information needed to answer the questions asked by policy makers, however it is also the job of research to help identify the questions that need to be asked. For indoor air quality both roles are important.

In trying to identify these information needs, we need to look not only at the physical nature of the Indoor Air Quality problems but also the institutional context in which institutions will use this information. Although major emphasis should be placed on the physical nature of the problem, the institutional context in which issues are resolved and problems solved cannot be ignored.

Physical Nature of the Indoor Air Quality Problems

Two examples show how the physical nature of the problem can drastically affect policy decisions. Let us look at two pollutants, radon and carbon monoxide. Radon is a naturally occurring noble gas. It is generated by the decay of radium, an element commonly found in small amounts throughout the earth crust. When radon is generated it easily moves through soil and building materials, and becomes part of the gas mixture that makes up the breathable air of a structure. Once there, it decays into a series of sticky metal particulates which if inhaled will lodge in the lungs. These particulates serve as internal alpha emitters and can therefore, result in an increased occurrence of lung cancer. Lung cancer from radon is not an insignificant problem; for after smoking, radon and its progeny are probably the single most important contributing factor to this disease.

Contrast radon with CO, another indoor pollutant. Indoor CO problems are primarily a product of fixed combustion sources found within the home. Adequately venting these sources can make controlling CO a stamped and straight forward problem to deal with. I think it should be apparent that the policy issues surrounding the management of radon would be significantly different from these for CO; and that difference lies is the differences in the physical natures of the pollutants.

Three variables affect the concentration of indoor air pollutants in a structure. These variables are: source term, ventilation rate, and extinction rate.

How we choose to manage Indoor Air Quality depends greatly upon which variable becomes dominant for a given pollutant. If the source term is a dominant element, then sources become the target for management. Since a wide variety of pollutants come from a wide variety of sources, a wide variety of different mediating measures may be required if we are to deal with the general problem of indoor air quality.

If, however, the ventilation rate is the dominant factor, then one may be able to deal with indoor air pollutants simply by controlling the air exchange rates. If this is achieved with the aid of an air-to-air heat exchanger, the energy penalty can be minimized.

If neither source nor ventilation rate is dominant, we may find that many pollutants can best be addressed by a device that will accelerate the extinction rate. For example, it may be possible to address a whole series of particulates, with an electrostatic precipitator or another type of filtering device. We may find, however, that a device that accelerates the extinction rate allows us to deal with classes of pollutants in some cases but only individual substances in others.

Depending upon which factor dominates a given pollutant, the nature of the programs and policies needed for its management will be quite different. Thus, it becomes very important to determine all three characteristics for any given pollutant.

At this point, I should raise the question: Is indoor air quality a generic problem or simply a series of related but individual problems? Agencies will find this question difficult to address. From a bureaucratic standpoint, it would be helpful to deal with pollutants as a group, instead of having to deal with a complicated decision process for each individual pollutant. This may be easier and a simpler way to approach the problem but if it does not reflect the physical reality of indoor air pollution, then it is an approach bound to fail.

Institutional Context of the Indoor Air Quality Problem

The research needs for indoor air pollution must also be addressed from the institutional context of the Agencies which will be responsible for managing the problem. The major components to an Agency's institutional context are its legal mandate, its internal policies and procedures, its budget, and the general political climate in which it must operate. EPA is primarily a regulatory Agency. We do, however, seek nonregulatory solutions to environment problems when we feel it is constant with our legal responsibilities and in the public interest. This is how we are approaching the questions of indoor air quality. EPA does not have, nor do we have plans for, a regulatory program for indoor air quality. The Agency feels more information is necessary before EPA can decide whether either regulatory of nonregulatory action is called for. We are currently actively engaged in a research effort to provide us with this information.

One of the activities we are engaged in is a review of our current authorities with respect to Indoor Air Quality.

EPA's present authorities include the following:

- The Federal Insecticide, Fungicide and Rodenticide Act, which includes labeling and restricting the use of many pesticides that could be characterized as indoor air pollutants.

- Drinking water standards which could control radon levels in drinking water. Radon in drinking water can represent a significant source of radon within structures.

- The Resource Conservation and Recovery Act which controls the use of building materials made from recovered or recycled wastes, and which could address the radon problem as it relates to the use of phosphate slag, zircon sands, and other materials that are manufactured from waste high in radium.

- The Uranium Mill Tailings Radiation Control Act, which allows EPA to write standards for the cleanup of lands contaminated from uranium mill tailings.

- The Federal Radiation Guidance Authority, an advisory activitiy that allows EPA to draft orders which, when signed by the president, regulates activities of other Federal Agencies.

- The National Environment Policy Act, which gives EPA the authority to review Environmental Impact Statements and major policy and regulatory activities of other agencies.

The Clean Air Act, which gives EPA authority to regulate ambient air, was omitted because "ambient" air has been defined by EPA as outside air. However, the Government Accounting Office report on indoor air quality has suggested that the Clean Air Act be changed to give EPA greater flexibility or responsibility in indoor air quality.

Although EPA does have some regulatory authorities, the Agency will show great caution in approaching this problem in a regulatory manner. To make a determination that a regulation is needed is an expensive and time-consuming exercise. It generally requires the development of exposure assessment and an assessment of health risk including estimate of the risk to the maximally exposed individual, risk to the population exposed, and an estimate of the total number of health effects involved. Also needed is an assessment of the potential for abatement of the costs and the impacts associated with instituting controls and, of course, a careful delineation and analysis of alternatives. This may require up to 3 years of study and a cost of a million dollars before EPA decides it should take action.

Procedurally, before we can establish a regulation, EPA must prepare a development plan and an advance notice of proposed rulemaking, and these must be reviewed by a work group and a steering committee and approved by the Administration. Once the development plan is prepared, development can begin on the proposed rule. The proposed rule, again, must be reviewed by a work group, then be approved by a steering committee and a red border review process. It must then be signed by the administrator. A period of public comment and, possibly, a peer review by the Science Advisory Board may follow. After the public review, we revise the rule as necessary and start all over again. Work Group, Steering Committee, Red Border, etc. To initiate such an effort cannot be taken lightly, particularly if no regulatory approaches can be instituted more quickly and effectively.

Competing priorities, budget and staff, political climate, public attitude, and legal mandates all contribute to defining the institutional context of an issue. It is this context that must be kept in mind as the research program for indoor air quality is formulated and executed.

Let me add one final observation, on the status of Indoor Air Quality. Indoor Air Quality is clearly recognized as an established issue by many Federal and state governmental institutions. However, I think it is fair to say, that these same institutions do not yet recognize indoor air quality as a major problem. The distinction between a problem and a issue is that issues are political entities that must be resolve but problems are physical entities and should be solved. I do not see that decision makers are willing to accept at this time that Indoor Air Quality imposes a clear and present danger for enough people or from enough pollutants to make Indoor Air Quality a problem that can compete successfully with other priorities. Consequently, a primary short term goal of indoor air quality research should be the identification and characterization of major pollutants in the indoor air. Not until a more thorough and adequate assessment of indoor air pollution risks is executed can decision makers be expected to accept these pollutants as problems that require significant actions. For this reason, we need a clear statement coming from our research effort which establishes the extent to which the risks are real and identifies the possible remedial measures that can be taken to reduce such risk. These are the questions that the research community must answer, and must answer quickly.

Mr. Howard Ross, Department of Energy:

Department of Energy Policy

DOE currently bases its policy on its Indoor Air Quality research conducted over the last 5 years, totaling more than 6 million dollars. Five main points emerge from that research:

1. Technology exists today to build a cost-effective airtight home with a winter air exchange rate of two-tenths of an air change per hour, or less.

2. Technology does not exist today to cost-effectively retrofit existing homes to reach the same levels of air exchange. Typically, retrofitting reduces air infiltration rates by 10 to 20 percent--in some cases 25 percent.

3. New homes are the principal concern regarding indoor air problems. They are much tighter with much newer furnishings and building materials off gassing more pollutants. Similarly, new commercial buildings with lower ventilation and infiltration rates are of greater concern than existing commercial buildings.

4. Selection of a standard ventilation rate will not guarantee lower indoor air pollution levels. Determining a building's ventilation rate is not a reasonable surrogate for measurement of the indoor air pollution levels.

5. The general solutions to the indoor air quality problem will be source control--either removal or reduction--or ventilation very near the source.

A Context for Remedial Indoor Air Pollution Control Actions

Infiltration by definition is when outdoor air leaks unintentionally through imperfections in the shell of a closed building. Intentionally opening a window or door provides natural ventilation. A window fan or an air-to-air heat exchanger provides mechanical ventilation. Each has different implications for building design.

Reducing the infiltration rates in existing homes is a difficult problem. Windows and doors are only 20 percent of the problem; most of the problems are hidden from the homeowner's view, and thus left unattended. Yet DOE research has found many sites of air leakage. In most homes, a person can sweep back the insulation in the attic and find large holes in the attic floor which leak air. Or, a light fixture can be pulled off to find a large hole which just a few wires pass through. Hundreds of other imperfections can be found in residential buildings. Homeowners simply cannot plug all of them.

One well known study shows that the average reduction in the infiltration rate by retrofit was 15 percent until diagnostic instrumentation was used to determine the leaks. An infrared thermographic camera used by energy auditing firms costs $7,500, and it can locate hot and cold spots in the building, otherwise invisible to the homeowner.

For existing homes, DOE recommends immediate remedial indoor air pollution control action in three kinds of situations:

1. For a home in an anomalous geographical area (e.g., a home built on uranium mill tailings or phosphate-reclaimed land) DOE recommends remedial action whenever caulking or weatherstripping is done.

2. If the house has poor design features such as an unvented gas stove or heater, remedial measures are necessary.

3. For those persons who have used instrumentation to find an air leak and then reduced the infiltration rates by a large amount, say 50 percent, remedial actions should be considered.

For the remaining homes not in these categories, DOE informs the homeowner of possible remedial actions but does not suggest that there necessarily is a need in all cases to spend $300 or more for an air-to-air heat exchanger or to buy an electrostatic precipitator. DOE cannot tell homeowners that spending this money on remedial actions is worthwhile and required to reduce serious health risks, for most homes do not have a grave indoor air problem. At this stage, DOE has decided that we have a duty to tell the public what we know about the subject. Unfortunately, what we know does not always permit straightforward, sound recommendations about what to buy, or if a particular home has a problem.

DOE encourages reducing the infiltration rate in all homes, but concurrently recommends remedial actions in those situations listed above. The results are increased comfort, increased structural integrity, reduced moisture condensation in the walls, and fuel bills are reduced. When outdoor pollution sources dominate, there is an indoor air quality benefit. In addition, conservative calculations show that a 25 percent reduction in air infiltration saves 10 to 15 million kilowatts of reduced peak power, or 10 to 15 new power plants probably nuclear or coal-powered, can be avoided.

Undoubtedly, people are aware of these benefits. A survey of 6,000 homes indicates that 41 percent of the people between April 1977 and December 1978 caulked, weatherstripped, or placed plastic over their windows. On Federal income tax forms, 1-1/2 million homeowners claimed that they bought caulking and weatherstripping. About 3 million more claimed storm windows.

The indoor air quality problem with existing homes differs from the problem with new homes. Today's builders have responded to the energy crisis (i.e., the market) by constructing tighter new homes. Yet, these new buildings are of more serious concern for possible indoor air pollution, due not only to these very low infiltration rates but to higher pollution source strength (new materials). For new residences, air-to-air heat exchangers are frequently touted as a panacea. An air-to-air heat exchanger fits in a window, is the size of a window air conditioner, costs $250 to $300, and recovers 50 to 80 percent of the heat in air which is being exhausted. Unfortunately, its durability and effectiveness under freezing conditions are not yet completely proven. DOE will continue to research its usage and promote its installation.

Governmental Action

The Government can regulate a number of factors that would affect indoor air quality. Infiltration rates, ventilation rates, indoor air pollution levels, material emission rates, and no smoking areas can all be legislated. Yet each would present a problem. For example, consider formaldehyde levels in a home. A recent study showed that when a home was unoccupied and without furniture, it was below the current Danish standard for indoor formaldehyde levels. When occupants moved in, the levels rose well above the standard. At night, when windows were open, formaldehyde levels dropped to just above the standard. Is the furniture or plywood manufacturer, the builder, the landlord, or the occupant at fault?

There is little hope or desire for regulating numerical standards for indoor air pollution levels. Therefore, DOE has opted to give information, and in certain cases, to recommend remedial action. DOE will recommend a long list of specific actions in a brochure that will be published soon. The consumer-oriented brochure tells homeowners both how to tighten their buildings and how to solve most indoor air pollution concerns.

DOE would like to recommend that homeowners have a measurement of radon and other pollutants taken in their homes. Yet, what should be said to a homeowner who finds 5 nanocuries per cubic meter of radon? No national health guidelines are in existence. Nor is there a guideline to suggest when remedial action is necessary.

DOE's Needs

DOE would like to see standards set by industry for infiltration in buildings. Airtight buildings can then be mechanically ventilated, which is a more energy-efficient way to provide ventilation and improve pollution control.

Next, DOE needs guidelines for indoor air pollution levels, and larger scale surveys of indoor air pollution levels. We may need to start some sort of massive information program if indoor air pollution is a widespread problem. In Sweden, where it is, I am told their radon problem is discussed on television.

DOE's Legislated Programs Relating to Indoor Air Quality

At present, DOE has five such programs, as follows:

1. The Residential Conservation Service* requires that utility companies offer all homeowners an onsite energy audit at a cost of $10 to $15. In addition, the utilities must give homeowners an estimate of the savings that will be realized with different retrofit measures including caulking, weatherstripping, and insulation.

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* The new administration has proposed cancellation of these regulation programs.

2. The energy tax credit which offers tax credits for insulation, caulking, and weatherstripping.

3. The proposed Building Energy Performance Standards* apply to all new buildings, establishing a maximum energy budget for those buildings.

4. The Low-Income Weatherization Grant Program retrofits about 30,000 homes with insulation, caulking, and weatherstripping.

5. The School and Hospital Grant Program provides for the Federal Government to pay for half the material and insulation costs of retrofitting existing schools and hospitals.

In addition, enabling legislation which formed DOE (and formally ERDA) allows research and development to be conducted in this field.

Dr. Irwin H. Billick, U.S. Department of Housing and Urban Development:

Concerns of the Department of Housing and Urban Development

What is the concern of the Department of Housing and Urban Development the quality of the indoor residential environment?

The concern arises from the national housing policy outlined in the Housing Act of 1949. This act declared that the general welfare and security of the Nation and the health and living standards of its people require housing production and related community development. Congress then stated that a decent home and a suitable living environment is the goal for every American family. However, HUD's jurisdiction over the housing of this country is limited to those programs that it supports either through insurance or through direct subsidies.

Indoor air quality obviously has not been the most important issue that HUD has pursued. Little thought was given by policymakers to indoor pollution arising from combustion products that come from fossil fuels, solvents that are used in household products, outgassing of chemicals from building materials, and other possible suspected carcinogens, mutagens, allergens, and other substances found in the indoor residential environment.

HUD, like most Agencies, is responsive to the immediate concerns of the country. For example, after the oil embargo of 1973, Government Agencies, builders and homeowners viewed thermal energy conservation as a means of combatting the rapidly rising costs of heating and cooking fuel. This led to structured and unstructured efforts to insulate housing and to decrease ventilation rates.

HUD provided monetary incentive for energy conservation through the HUD Minimum Property Standards, which mandated energy conservation measures as conditions for participating in HUD programs. At the same time, we learned that unacceptably high concentrations of pollutants such as radon and its progeny can exist in housing where air exchange rates were too low.

In response to this knowledge, HUD jointly sponsored with EPA the study of indoor air quality in the residential environment. HUD also is sponsoring several studies related to formaldehyde in mobile homes. These studies will be used to support Departmental standards and policies.

Currently, HUD has a cooperative agreement with the State of Montana to develop and evaluate methods for mitigating radiation hazards from radon infiltration. The Department has also published an advance notice of rulemaking related to setting air infiltration rates to be used in minimum property standards.

With one of the smallest research budgets and staff among the Federal Agencies, HUD must rely largely on the research of other Agencies for guidance in setting health related standards and guidelines. HUD's policymakers will ask for firmer evidence to support the decisions that affect indoor air quality. The scientific work used to support health effects, pollutant levels, and social and physical costs must be scientifically valid before research can be translated into a regulatory action, since such actions could severely impact both the cost and supply of housing.

HUD has a genuine desire to see that its programs do not inadvertantly create unhealthy or unsafe indoor climates through the unwise location, design of housing, or the use of certain materials in its construction. We also have a great desire to protect the health and welfare of our constituents. For this reason, HUD is depending on this workshop to assist in defining an interagency research agenda which will lead to the scientific information required to accomplishing its goals in the area of minimizing the effects of indoor air pollution.

Dr. Peter Preuss, Consumer Product Safety Commission:

Concerns of the Consumer Product Safety Commission

1. The decisionmakers in the Agency are five Commissioners appointed by the President. These Commissioners need to know if a problem exists with indoor air quality which necessitates expenditure of significant Commission resources. CPSC needs to know the degree to which the problem associated with indoor air quality is a general problem rather than one that is associated with specific consumer products or chemicals. Of greatest import is the need for a method for deciding which aspects of this problem require attention first rather than last.

2. We also need to clarify how the statutory responsibilities are divided among Federal Agencies. A fair division seems to exist between statutory responsibilities and authorities. Overlaps also exist. These must be clarified.

3. Finally, we need to resolve which Agencies are in fact going to be working on indoor air quality. Are these Agencies likely to cover the issues that concern CPSC? If so, perhaps there is a lesser need for CPSC to become involved. It is possible, however, that there are parts of the problem in which other Agencies have no interest or for which they lack statutory authority and which will fall on the shoulders of the CPSC.

At present in CPSC, one of the most important statutes applicable to indoor air quality is the Consumer Product Safety Act. This act allows CPSC to take action when a finding is made of unreasonable risk to health or safety. It provides a variety of regulatory options; e.g., labeling, setting a standard, or banning a specific product. In order to deal with the numerous products in its purview, CPSC has divided the Agency programs into a number of major hazard programs, two of which are involved to a significant degree with the question of indoor air quality. One relates to household structures, the other relates to the other sources of chemical hazards that may affect health. These two programs converge for tighter homes in which there may be increased levels of pollutants and household structures or materials themselves may emit a harmful substance.

We have divided the pollutants into two groups. The classical pollutants include nitrogen oxides, sulfur dioxide, and carbon monoxide, and a number of other products of combustion. The nonclassical include other chemicals (organic, particulates, etc.) generated by aerosols, deodorizers, cleansing products, and other consumer products that may introduce an unsafe level of pollution inside the home.

For example, many of you are familiar with the argument before the Supreme Court concerning the standard in which OSHA proposed to reduce the level of benzene in the workplace from 10 parts per million to 1 part per million. While that discussion was taking place, CPSC examined the levels of benzene that occur from the use of consumer products. Some time ago, CPSC proposed a regulation to eleminate the intentional addition of benzene to consumer products and to limit the contaminant level of benzene to 1/10 of 1 percent. That regulation was never promulgated, but today, no intentional benzene is added to consumer products. It does, however, remain as a contaminant, and laboratory work and modeling have been performed to determine the levels of benzene that still can be reached in homes. At very low air exchange rates, over a 50-hour time-weighted average, we measured and modeled levels of benzene that were significantly higher than 100 parts per million when benzene was present in a product at about 2 percent. Even when a product contained a tenth of a percent significant levels of benzene were measured.

Research Needs

CPSC has recommended an air pollution program in 1982. Before that program comes into effect, we need the following information:

- The levels of pollutants that are likely to be found in homes, particularly nonclassical pollutants
- The long term health effects of low levels of these pollutants
- The additive or synergistic health effects that could arise from the presence of two or more combined pollutants.

We also need a mechanism to integrate hazard and exposure information to help us determine study and regulatory priorities. It is easy to discuss research that can provide solutions in 5 to 10 years, but we need to determine which problems should be dealt with immediately.

Finally, it is extremely important in matters of policy to make sure that the Government Agencies are preparing a coherent research plan. This plan should be coordinated with the academic community, the industrial community, and with other parts of Government.

MONITORING INDOOR AIR QUALITY

The monitoring section is organized according to six categories:

- Aerosols (including fibers)
- Organics (including pesticides, PCBs, nitrosamines, and odors)
- Criteria Gases (plus CO_2)
- Radon
- Formaldehyde
- Statistics and Modeling.

Within each category, a brief introduction and discussion of measurement methods precedes the summary of the research needs. Details of the recommended research projects are listed in Appendix B.

A more detailed discussion of measurement methodologies (porous polymer adsorbents for organic vapors) is included as Appendix C.

In the final plenary meeting of the monitoring session, the combined groups identified four unifying themes:

1. The total exposure concept. A person's health can be affected by indoor, outdoor and in-vehicle exposure. The total exposure concept (i.e., 24-hour exposure) must be an integral part of all monitoring efforts if only to determine the relative contribution of the indoor air to that exposure. Another important consideration are the multimedia effects of water and food and the correlation of these data with body burden data (e.g., breath, blood, and urine levels).
2. Coordination. The complexity of the indoor air quality problem requires interagency cooperation; cooperation among health, monitoring, and instrumentation people; and interactions with industry, architects, builders and engineers, and Government.
3. Careful planning of field monitoring. Many examples exist of inadequately planned field studies that neglected to record the one item of information that latter was found to be necessary. Thus, there is a need to design monitoring studies that make precise statements about the objectives, protocols, data requirements, and interrelationships with other efforts planned or in progress in the public and private sector.

4. *The "sick building" concept*. Many panel members felt that there is a new and very real problem emerging in indoor air studies: buildings, including very large ones, in which considerable proportions of their inhabitants are affected adversely. Such buildings associated with outbreaks of disease or complaints present an opportunity to study a condition that affords a high probability of source identification, provided a thorough study can be launched.

AEROSOLS

INTRODUCTION

Instances of serious health effects from indoor air pollution have been reported nationwide. Public hearings in California have shown that these effects not only lead to morbidity, but also to significant economic losses to the victims. Aerosols are an important component of indoor air pollution, particularly those in the respirable size range, due to their persistence in the human lung for periods which may be as long as several months. Further, combustion-produced aerosols may contain large numbers of harmful organic substances. When ventilation is insufficient to control the indoor aerosol to levels that approximate clean outdoor air, indoor air pollution results.

Recent studies indicate that personal and indoor exposure to respirable particles (RSP) is greater than outdoor exposure. A number of instances have been reported around the country in which office buildings have been polluted to the point where they have become virtually uninhabitable, frequently in new, so-called energy efficient buildings which have been designed for substantially reduced ventilation. Typical indoor sources of aerosol, such as cooking, smoking, coughing, sneezing, flushing of toilets, flaking of asbestos building materials, vacuuming, office reproduction equipment, microbes, spores, and molds, and indoor traffic, will rise to higher concentrations and become more persistent with reduced ventilation. Indoor exposures to such agents need to be characterized chemically, physically, biologically, temporally, and spatially.

Particles

Monitoring programs for particles should have two main objectives:

1. Determine population exposure to particles
2. Define source contributions to individual and population exposures.

Knowledge gained in these two areas will:

1. Identify high-risk subpopulations
2. Define effective control strategies
3. Identify specific compounds for toxicologic or epidemiologic testing
4. Determine how well (or poorly) ambient outdoor levels compare with indoor or personal exposures.

Four basic types of monitoring studies are recommended:

1. Chamber studies to identify source strengths, composition, and decay rates

2. Case studies to determine spatial and temporal patterns within buildings as functions of activities, sources, and ventilation and air cleaning systems

3. Large scale surveys to define the distribution of sources and concentrations in a variety of indoor locations

4. Personal exposure studies to verify contributions from specific sources.

Certain supporting efforts must be mounted concurrently:

1. Development of instrumentation. In particular, increased sensitivity for shorter sampling times is desirable. This can be obtained either by increasing airflow (without increasing the size or noisiness of the pump) or by increasing the sensitivity of the analytical procedure. Another possibility is the use of one instrument (such as the Piezobalance or GCA Respirable Aerosol Monitor) to measure mass nearly instantaneously, and a second instrument to collect the particles for chemical analysis.

2. Time-motion studies of populations. This is required both to plan monitoring efforts and to interpret and extrapolate their results to the population at large.

3. Models of particle behavior. Included here are indoor-outdoor models, as well as models of the transport, growth, decay, and deposition of particles.

4. Models of personal exposure. These models could combine the results of monitoring, physical models of particle behavior, and "sociological" time-motion studies to estimate total exposure.

5. Inducements for volunteers. Participation from all socioeconomic classes is required to make these studies representative of the population exposure. To date, participation has been limited to narrow socioeconomic and occupational ranges.

ORGANICS, NITROSAMINES, PESTICIDES AND ODORS

INTRODUCTION

Organic compounds in indoor air are numerous, not well understood, and could contribute strongly to effects on health and well-being. Major sources include heating and cooking, pesticide use, and common products in homes, offices, and vehicles.

The group considered four major classes:

1. Volatile organics. These low molecular weight compounds include many of the most important carcinogens such as benzene, trichloroethylene and tetrachloroethylene. Major sources include the automobile, dry cleaning, painting and refinishing.
2. Pesticides and PCBs. These semivolatile organics are used extensively in homes and yards. A major source of PCBs may be burned-out ballasts from fluorescent lights.
3. Nitrosamines and Hydrazine. Major sources of these compounds include cooking, washing, rubber products, tobacco smoking, and auto exhaust.
4. Odors. These may serve as indicators of previously undetected pollution sources, such as abandoned waste sites.

Volatile Organics

It was generally felt that the use of Tenax GC procedures involves considerable experimental uncertainties. These are addressed in the section on "State of the Art in Organic Vapor Monitoring."

The following specific monitoring efforts were suggested:

1. Extensive investigation of episodic emissons from household appliances and activities, such as woodburning stoves, fireplaces and spaceheaters, cooking, home repair such as painting, varnishing, refinishing furniture, waxing, or cleaning.
2. Complete exposure assessment correlating breath analysis and possibly blood levels with ambient air concentrations.
3. Analysis of phthalates and phthalate acid esters from automobile interiors. This is conditional on demonstration that these compounds are collectable and desorbable from Tenax GC.

4. Complete characterization study of Tenax GC including sampling, desorption, analysis, and characterization of compounds' collection and desorption efficiencies.

5. Characterization and source identifcation of organic materials in office buildings. Many complaints concerning air quality in new office buildings are being received and this needs immediate attention.

6. Headspace analysis of construction and building materials. The purpose of this study would be to isolate sources of specific contaminants and thus provide focal points for control measures.

Pesticides

The methodology for study of semivolatile organics has progressed from the ethylene glycol method to polyurethane foam collectors followed by GC/MS analysis. Desirable improvements include automation of the sample elution and analysis to increase throughput. A personal sampling method is needed; present equipment is too bulky and cumbersome. Analytical procedures need to be developed for synthetic pyrothenes and carbamates. Finally, a method is needed which will allow for separation of airborne pesticides and organics from those entrained on particles. No satisfactory method exists for this purpose.

Some of the specific monitoring efforts suggested include:

1. A study of PCB sources and the spatial pattern of PCB concentrations in homes. Evidence to date suggests that PCB levels are higher in the kitchen than in other parts of the house.

2. A monitoring study to determine the extent of continuation resulting from home pesticide use. A large-scale (10,000 homes) survey of home pesticides use will be conducted in the very near future, and modification of the protocol would allow a monitoring component to be added to the study. Body burden should also be a component of this study.

Odors

Odor is probably the most common and best early warning signal of potential problems stemming from polluted water, leakage from chemical waste disposal sites into the home or other previously unrecognized sources of air contamination. Fortunately, the state of the art in odor measurement using trained human panels is fairly well developed. Unfortunately, this technology is only slowly gaining acceptance by the regulatory Agencies, notably in Texas. The most obvious odor problems stem from outside sources such as rendering plants, feed lots, and a variety of other industrial operations. Other sources of odors which may lead to health problems or be indicative of health problems are building materials (formaldehyde, water-based paints, etc.), consumer products, dead animals, transformer burnouts, ink and paper products, smoking, etc.

Specific monitoring efforts suggested include:

1. Determination of the impact of outdoor odors on indoor environments. This could be in the form of a survey of regulatory Agency complaints followed up by specific monitoring efforts.
2. Establishment of a protocol for classifying and handling odor complaints. Not all odor complaints are nuisance complaints; some may be real hazards, such as odors associated with hazardous waste disposal (e.g., Love Canal).

Nitrosamines

The primary collection method involves a specially designed collector which traps nitrosamines from an air stream chemically, but allows NO_2 to pass through, thereby lessening the opportunities for in situ formation of nitrosamines from reaction of NO_2 and amine-containing compounds. The collector can be used for practically any length of time with the shortest time dictated by the sensitivity of the analysis system.

Elution of collected samples is accomplished by passing 1 ml of solvent through the collector into a standard septum vial. This vial can then be used in standard carousel auto injectors. This greatly speeds the analysis and allows for high productivity. The analysis can be performed by GC, GC/MS, or TEA analyzers. The TEA is probably preferred as it is specially designed for nitrosamine analyses.

Nitrosamines exist as contaminants in certain products found in the home, namely, rubberized materials such as indoor/outdoor carpeting and upholstery. Automobiles also contain a large number of materials contaminated with nitrosamines.

Nitrosamines are also present in ambient air as a result of activities in which situations exist that promote their formation. These situations include cooking with gas appliances and passive and active smoking of tobacco.

Research Needs

1. A thorough investigation of nitrosamine formation during cooking and investigation of possible methods of control. Specifically, what are the differential concentrations of nitrosamines in kitchen air as a result of:
    - Cooking with gas stoves versus electric ranges
    - Cooking meats and other greasy foods

  - Using vented versus unvented appliances
  - Using various types of filters that may control nitrosamines, especially the residence time in the indoor environment

2. Investigate the concentration of nitrosamines in public smoking versus nonsmoking areas

3. Determine the source of nitrosamines and to what extent these sources impact on overall air quality in homes, offices, etc. What effect does ventilation have on the concentration of nitrosamines? Decay rates?

4. Extent of exposure in automobiles and other modes of transportation.

One further monitoring effort was suggested which would involve monitoring the levels of exposure of individuals by personal monitoring for nitrosamines and other nitro-organic compounds, including hydrazine. Hydrazine has not been studied extensively and the extent to which this carcinogen exists in ambient air has not been characterized. A monitoring study on hydrazine seems warranted.

RADON

INTRODUCTION

One of the most important indoor pollutants is radon, a naturally-occurring radioactive element, and its progeny (the products of radioactive decay). The risks of given large exposures are better known for these substances than for any other indoor pollutant, and therefore monitoring programs to determine the extent of population exposure will simultaneously determine the overall risk associated with radon.

There is a need to establish quality assurance procedures and instrument evaluation and validation in the monitoring of radon and its progeny. Efforts in these areas have begun but need to be established on a formal basis. Existing instrumentation is not optimal. There is a particular need for inexpensive passive radon progeny and working level measuring devices and for less expensive real time working level and progeny monitors.

Substantial research efforts are needed in four areas. Studies of indoor radon and radon progeny concentrations should be undertaken to understand their dynamic behavior in buildings and to determine the range and distribution of radon and/or its progeny in the Nation's building stock. Before proceeding with a large scale survey, it is necessary to evaluate the usefulness of various passive techniques for characterizing the concentrations of radon and/or radon progeny in residences, and to assess the viability of short-term measurements to represent annual averages. Finally, it is necessary to characterize radon sources and ground transport in order to provide predictive capabilities for indoor concentrations of radon/radon progeny.

Although there is an urgent need to assess the seriousness of radon/radon progeny problems indoors and survey the existing housing stock, it is important to proceed carefully to collect data which will be useful in and adequate for making these assessments. In order to assess the impact of programs such as energy conservation retrofits, information on parameters such as air exchange rate may be required. To proceed with these studies requires three levels of research: (1) detailed studies need to be performed in a laboratory or research-house environment in order to characterize radon behavior and establish measurement protocols, (2) these must be validated in moderate-sized field sampling programs before surveys on a national scale are performed, and (3) attempts should be made to coordinate large-scale radon surveys with other large-scale surveys such as energy conservation audits or other indoor air quality studies.

Research Needs

1. Study the behavior of radon and radon progeny indoors. Intensive studies in a few research houses will serve as a basis for designing and interpreting field studies

and surveys. These houses will be instrumented to study continuously radon and radon progeny concentrations, infiltration/ventilation rates, radon progeny and particulate interactions and size distributions, removal processes, the effects of temperature, humidity, and particulate levels, and the effects of HVAC system operation and various control strategies. Existing instrumentation except, perhaps, in progeny/particle interaction work, is sufficient for these studies. The estimated time required is 3 years at $300K per year.

2. Evaluate passive monitoring techniques. Before proceeding with large-scale surveys it is necessary to evaluate the usefulness of various passive techniques for characterizing the concentrations of radon and radon progeny in residences. The purpose of this study is to assess the viability of surrogate (short-term) measurements to estimate annual average concentratons and indoor exposures. Current studies in places, such as Butte, Montana, where many detailed measurements are being made over a 1-year period, can serve as a starting point for this study. Other studies are needed on a progressively larger scale. Parameters to be measured include radon and radon-progeny concentrations on a real-time and integrated basis, infiltration/ventilation rates, and radon flux from the soil. These parameters will be monitored for a period of 1 year to determine the feasibility of and to establish protocols for shorter term integrated monitoring. This project is estimated to last 3 years at $250K per year.

3. Designing and implementing a national radon survey. In this survey a sufficient number of homes in the United States would be monitored, with adequate sample stratification, to project the extent of the U.S. indoor exposure to radon and radon progeny. Existing passive monitors for radon are currently being evaluated, but passive working level monitors are needed if working level measurements are deemed necessary. The recommended survey will aid in making program decisions and in determining the need for guidelines and standards. It is estimated that a survey of this scope would take 2 to 3 years at a total cost of $1M.

4. Studies of radon sources and ground transport. This research would provide predictive capabilities for indoor radon and radon progeny concentrations. By determining the relevant parameters that contribute to high indoor concentrations in residences and by understanding the mechanisms through which radon enters the building spaces, builders could possibly eliminate the construction of houses with elevated indoor

radon levels. Parameters to be measured include radium content in soil, radon concentrations in soil gas, radon diffusion lengths, and the effects of groundwater and moisture, atmospheric pressure, and temperature. It is necessary to determine the temporal variations in these parameters. In addition, the feasibility of making a large-scale grid survey of radon concentrations over the continental United States to determine the variations and identify regional hot spots will be assessed. These studies are estimated to last 3 to 4 years at $250K per year.

FORMALDEHYDE

INTRODUCTION

Although formaldehyde is part of the overall air quality (and organics) issue, it must be recognized that it is a very special pollutant by comparison with other pollutants because of its high chemical reactivity. Also, due to the high level of public interest, formaldehyde warrants individual attention. Monitoring of formaldehyde is extremely difficult because of the influence of temperature, humidity, and history upon its emission. Refinement is needed in both sampling methodology and analytical methods in the long term. There is an urgent need for immediate measurements to determine the extent of the formaldehyde problem. The monitoring program will depend on the detection level required, that is, for irritation or for carcinogenic effects.

Measurement Methods--Capabilities and Needs

- Sufficient capability exists for industrial hygiene monitoring but not for ambient indoor air monitoring.
- The NIOSH measurement limit is 0.5 ppm but much lower levels can be detected with new devices; a 0.03 ppm low level limit would be sufficient to satisfy all concerns.
- Investigators currently doing work in formaldehyde monitoring should convene to compare equipment performance and coordinate present and future activities.
- There is no standard source of formaldehyde, which makes calibration and comparison difficult. (The particleboard industry does have round-robin testing underway for several products.)

Research Needs

1. Establishment of a measurement protocol for air monitoring. Measurement simultaneously of other pollutants which create similar symptoms is a necessary ingredient in this proposal. Also, round-robin calibration should be incorporated.
2. Development of a low cost, short time (8 hour), inexpensive dosimeter that can be used to begin to establish a data base on a broad scale.
3. Development of continuous, real time instrumentation should be continued.
4. Investigation of biological methods as a means of increasing the sensitivity of formaldehyde measurement.

CRITERIA GASES (PLUS CO_2)

INTRODUCTION

Five major pollutants were included in this category. Their importance relative to indoor air pollution will be discussed singly.

Carbon Monoxide--Since outdoor CO levels in several urban areas exceed levels at which adverse health effects can occur, IAQ studies to determine exposure to CO should be a high priority. Indoor exposures are important because outdoor CO penetrates readily and is added to contributions from indoor sources such as gas stoves, attached garages, smoking, and unvented heaters. In-vehicle exposure should be looked at concurrently with IAQ studies as motor vehicles are the most important source of CO. Work and recreation exposures may sometimes be important, requiring determination of total human exposure to CO in future monitoring studies.

Nitrogen Dioxide--Indoor levels of NO_2 tend to be dominated by indoor combustion sources such as unvented gas stoves and fuel-fired heaters. Much has already been published on this effect. More work is needed in defining total human exposure in terms of short- and long-term exposures. In addition, instrumentation should be developed for examining total human exposure to NO_2. Parallel health effects studies would also contribute to an enhanced understanding of the dynamics of this gas.

Sulfur Dioxide--Except for special circumstancs such as leaky heating systems, indoor SO_2 levels do not appear to require special attention. Indoor SO_2 and sulfate levels should be surveyed in several nonattainment areas.

Ozone--Indoor concentrations of O_3 are usually a small fraction of those outdoors except in those rare instances where indoor sources (e.g., electrostatic precipitators and copying machines) may produce elevated indoor levels. Therefore, monitoring programs to further define indoor O_3 levels are of low priority.

Carbon Dioxide--Indoor sources such as human occupancy, gas stoves, and unvented heaters can add to the preexisting relatively high CO_2 background. There is a need for monitoring programs to identify possible critical situations; for example, modification for energy-saving purposes of older buildings with inadequate ventilation systems, or use of unvented heaters. Again, parallel health studies are needed.

Measurement Methods--Instrumentation for continuously measuring outdoor levels of criteria pollutants is at an advanced state of technological development. However, further work needs to be done in evaluating available instruments for monitoring indoors, especially in view of the potentially large number of compounds in the indoor atmosphere that could interfere with the response of these available instruments.

The state of the art in small portable or personal devices (including passive monitors) suitable for total human exposure studies is not advanced. There is a critical need for devices that are capable of measuring both short- and long-term exposures to a variety of pollutants.

Relationships to Ambient Air Quality Standards

The relationship to indoor air quality of the outdoor National Ambient Air Quality Standards (NAAQS) is not clear. Since indoor air quality standards are not likely in the foreseeable future, the contribution of IAQ monitoring programs will lie in better defining total human exposure. The results of such programs could then be evaluated with respect to the NAAQSs as a means of developing more meaningful total exposure air quality standards.

Types of Monitoring Programs

Seven types of monitoring programs were identified:

1. Source Strength Measurements
2. Indoor/Outdoor Characterization Studies (for various types of structures, activities, and energy conservation practices)
3. Indoor Episodic Situations (e.g., stove use, furnace leaks, product usage, etc.)
4. Epidemiologic Studies (e.g., six-cities study)
5. Human Exposure Characterization
6. Chamber Studies (e.g., source impact on exposure of subjects)
7. Comparative Monitoring Programs (determining accuracy, sensitivity, interferences, and response of instrumentation).

RESEARCH NEEDS

Research needs are presented in terms of eight specific projects. The titles are listed as follows, and a description of each is presented in Appendix A.

1. Human Exposure to CO
2. Screening Study to Determine Total Human Exposure to NO_2 Using Passive Monitors
3. Human Exposure to both Short- and Long-Term Average Concentration of NO_2 (Instrumentation is not yet available for this study)

4. Establishment of a Research House or Chamber to Determine Fate of Emissions from Combustion Appliances

5. Assess Impact on IAQ of Alternate Space Heating Systems (Coal stoves and kerosene heaters)

6. Evaluation and Calibration of Monitoring Instruments for Application in IAQ Studies

7. Assessing the Importance of CO_2 Concentrations in Crowded Rooms with Insufficient Ventilation

8. Development and Evaluation of a Simple Broad Spectrum Sensing Device for the Rapid Detection of Degraded IAQ from Combustion Effluents.

STATISTICS AND MODELING

INTRODUCTION

Certain statistical techniques that will be required for indoor monitoring programs are not well developed. Thus, several of the detailed research proposals deal with this need. Similarly, existing physical indoor-outdoor air quality models have not been validated in residences, and such validation is suggested in other detailed proposals. Other topics identified were:

- Relationship between monitoring to support health studies and monitoring to support regulatory needs. Health scientists and physical scientists should coordinate with one another in designing monitoring studies.
- Mobility patterns and time budgets as they are needed to extrapolate exposure measurements to a wider population.
- Exposure models incorporating mobility patterns and physical models.
- Air filtration rates as they relate to energy conservation and indoor air quality (particularly the relationship with indoor source emission strengths).
- Characterization of building design and materials as they affect indoor air quality.
- Statistical designs for large studies (as opposed to pilot studies).
- Use of data collected for several purposes.

REPORT OF THE INSTRUMENTATION SUBGROUP OF INDOOR AIR QUALITY

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DISCLAIMER

The contents of this report include comments received during the workshop and do not necessarily represent the views of a single author or his/her employer.

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Attached to the report is a list of participants. The authors thank the many people at the workshop who provided interesting and provocative input to the discussions.

Section 1.0

ABSTRACT

The following seven sections describe an initial attempt to formulate a research strategy plan to begin the development of a comprehensive program for developing sampling and analytical methods for hazardous chemical and physical agents which people are exposed to in enclosed structures like residences, offices, and public buildings. The plan calls for the development of instrument requirements, quality assurance programs for analytical laboratories, new and intelligent portable instruments, and Government regulations or guidelines so that instrument manufacturers recognize a market.

An inventory of ongoing IAQ or related research is included. Where the working group felt there were omissions, projects were suggested.

Section 2.0

SUMMARY OF THE SESSION

The Instrumentation working group was composed of distinguished scientists from Government, national laboratories, and private industry. Unfortunately, the academic community or a representative from the National Science Foundation was not represented.

The working group began by a self-introduction and description of one's personal or related experience in instrumentation relating to Indoor Air Quality. As instructed, we then discussed the strategy plan.

This was followed by a review of the Inventory of Indoor Air Quality Research, where the group found several instances of projects relevant to Instrumentation. More than a half-dozen additional projects were added to the list. The group of more than 30 people then broke into smaller units (Table 2-1) to review the state of the art and identify research needs as they relate to the general topics of Table 2-2. Time, and sometimes lack of an expert, prevented the group from addressing all the issues.

Table 2-1

- Aerosols (mass size)
- Organics
- Inorganics
- Radiation
- Biological (no expertise)
- Comfort (no expertise)
- Control Instruments
- Quality Assurance

Table 2-2

- State-of-the-art
- Source Emissions
- Chemical and Physical Interactions
- Transport and Removal
- Monitoring
- Quality Control

Efforts were made to work with the monitoring group; continuing coordination is necessary. Some of our smaller units were able to make contact with others in different working groups which helped increase our dialogue. Upon completion of the working sessions, the units prepared a brief report for the final plenary meeting.

The instrument working group offered these constructive remarks.

- Schedule the working groups in such a way that participants can contribute to more than one topical area
- Have the working groups closer to each other
- Future workshops on these subjects should focus on a specific area or issue.

The subject of an international symposium on indoor air quality was discussed. Feelings were mixed but generally cool to such a conference. However, several useful suggestions were offered such as having the conference followed by a workshop, and having it in conjunction with a professional society meeting (polarized response to this suggestion).

Section 3.0

REVIEW OF THE STATE OF THE ART AND STATE-OF-THE-ART PAPER

3.1 OVERVIEW

The quality of the air we breathe and the effects of air pollution on human health have been a major concern of health officials and the public for years. Already research and regulatory Agencies have been involved in measuring the effects of air pollution and enforcing standards in indoor environments as well as outdoor. There are several reported cases of new buildings where employees working inside these buildings became ill as a result of emissions from building products. The Occupational Safety and Health Administration and the National Institute for Occupational Safety and Health have assisted in determining the causes of the illness. Changes in building practice in the United States, as a result of energy conservation measures, are allowing fewer air exchanges in residential and commercial buildings. Concomitantly, there will no longer be a dilution of the building emissions, and chemical concentrations may reach hazardous levels.

As a result of these concerns, a comprehensive program is being formulated by several Agencies which have experience or responsibilities in this area. One area of concern is that of instrumentation needed to carry out the monitoring functions of the program. The Subcommittee on Instrumentation is responsible for quality assurance, development, and validation of sampling and analytical methods and development and evaluation (in both laboratory and field) of instruments for monitoring and control of pollutants. This would include instruments or methods to measure emission products and their emission rates from building materials.

As in industrial hygiene, monitoring and instrumentation are closely linked. Valid sampling and analytical methods are required to obtain estimates of individual exposure to pollutants for research needs, risk assessment, and compliance with existing standards. It also seems likely that guidelines will be developed for building ventilation rates and emission rates from building materials. Valid methods and performance specifications will need to be established for these physical/chemical measurements.

A large assortment of monitoring devices which were not available to the industrial hygiene community in the 1970s are now commercially available. The application of century-old kinetic theories such as Fick's Law are providing gas monitoring systems which do not require mechanical pumps. Some of these passive monitors, as they are sometimes called, may contain liquids and therefore provide ideal replacements for the frequently criticized bubbler samplers. These new devices have not yet been validated, nor have any formal sampling and analytical methods been developed for their use by a Government Agency or consensus standard organization.

The recent introduction of microprocessor controlled chemical and physical agent monitors will force the rethinking of how some elements of industrial hygiene and environmental monitoring will be done in the future. These devices offer the potential to combine into nearly a single operation the collection, the analysis, and the recording of pollutant levels. They can also compare the exposure to established standards and alert the worker or responsible officials of potential problems. As the monitoring devices become more intelligent, highly skilled environmental scientists will be free to spend more of their time developing mechanisms to reduce exposure to chemical and physical hazards and to assess the quality of life of the U.S. population. Personnel with less training can be used to collect the samples and thereby ease any shortage of industrial hygienists or environmental scientists.

Recordkeeping will be simplified because these computerized instruments have the power to process the data and present them in a format tailored to individual needs. This, again, eliminates mundane chores and permits attentions to be directed to studying exposure trends and the health of the population. Furthermore, there will be more information available on the nature of exposure, which was not previously available to epidemiologists and health officials. Hopefully this information will increase the accuracy of our decisions when determining risk and setting standards or guidelines. At stake is our nation's health and quality of life.

The new instruments, like their passive monitor counterparts, are just now being evaluated by several agencies (including NIOSH, DOE, EPA, BOM), insurance companies, university scientists, etc. Their utility must be examined for application to the indoor air quality program, where it is expected that concentrations of these pollutants will generally be lower than workplace concentrations. The largest collection of sampling and analytical methods for chemical pollutants is published by NIOSH (NIOSH Manual of Analytical Methods, second edition in six volumes). This manual describes more than 400 sampling and analytical methods. A companion publication summarizes a program to validate many of the monitoring methods (NIOSH publication 80-133). These two publications can form the basis for launching an indoor air quality monitoring program; extension of the range of the methods and conversion from pump-collected to diffusion-based sampling will be needed. Quite naturally, the methods must conform to the demands of the monitoring strategies proposed by the Monitoring Subcommittee. Sampling periods ranging from a fraction of a day to a week or longer may be required. Some of the places to be monitored, because of their proximity to different industrial or chemical dumps, will need surveys made to identify the composition of the indoor air in more detail. Monitoring methods and portable instrumentation will be required to makes these surveys.

Recent United States Supreme Court rulings have had significant impact on the current approach to establishing workplace and possibly other health standards. It appears that health research institutions and regulatory Agencies will be required to accurately quantify specific risks to individual populations and relate them to specific exposure levels. Current exposure and environmental data will form the framework for establishing these standards and their technologic feasibility. As always, the quality of the data is important. The sampling must be properly done and the exposed population specified. The laboratories engaged in performing the analysis should have quality control practices in place and demonstrate their proficiency through participation in the various interlaboratory quality assurance programs. The portable, direct-reading monitors can create special problems in calibration, and hence in the accuracy of data. The direct-reading units transfer quality control of the analysis from the confines of a centralized analytical laboratory to satellite operations or to monitoring sites. Therefore, in the coming years field usable standards will be needed for these instruments, and the proficiency and quality assurance programs must take appropriate steps to accommodate these trends. Protocols for the instruments, like the sampling and analytical methods, are essential. The protocols should include consistent methods for their use and evaluation.

Currently, it is unclear what the magnitude of the monitoring program will be. It is clear, that with some of the recent developments in monitoring, there could be a significant backlog in analysis of the samples. Research will be required to incease sample throughput. It is not unlikely that hundreds of thousands of analyses will be performed each year. This increase in analysis cannot be accommodated by just building larger labs to accommodate slow analytical procedures. Methods and instruments to speed the analyses will be needed. Laboratory automation and recordkeeping systems will be essential.

The Environmental Protection Agency's October 1980 Indoor Air Quality Research Strategy Plan calls for a Taxonomy of Instrument Needs. This can start by defining in broad terms what some of the requirements are. That is: laboratory or field instruments, degree of specificity, accuracy, weight, etc. This effort can be expedited by making current such instrument compendia as the Lawrence Berkeley Laboratory's "Survey of Instrumentation for Environmental Monitoring," and the American Conference of Governmental Industrial Hygienists' "Air Sampling Instruments for Evaluation of Atmospheric Contaminants." Table 3-1 lists several of the contaminants from the EPA research plan and the availability of samping and analytical methodology and instruments which are now available or can be easily adapted to measure them.

Besides environmental assessments, instruments and protocols will be required to measure air exchange rates in commercial-sized and residential structures. This is currently being done using gas chromatography or infrared spectrophotometry. It is not clear at this time if exact protocols have been established so that the scientific community can perform comparisons of studies conducted by different groups.

Table 3-1.

Substance	Method	Medium-Procedure	Range	Sampling Time	Research Needs	(Tubes or Direct-Reading) Instrument
1. Asbestos	P&CAM 239	Filter-Microscopic Count	0.1-60 fibers/cm^2	Varies	Fiber Sizing and Type	GCA-Fibrous Aerosol Monitor (FAM)
2. Silica	P&CAM 109	Membrane Filter-X-ray Diffraction	5-200 g/cm^2	Varies		
3. Manmade Fibers					Development Work Required	GCA-FAM
4. Nuisance Dust, Tobacco, Main and Side Stream	S 29	Filter-Weight Diff. Cyclone-Respirable Dust		1-8 hrs.		GCA-Aerosol Monitors TSI Aerosol Monitors
5. Sulfur Dioxide	P&CAM 146	Impinger-Titration	0.01-10 ppm	Up to 100 min. at 1 l/min. sampling rate		
	P&CAM 160	Impinger-Colorimetric	0.003-5 ppm	Up to 25 min. at 0.2 l/min.	Needs strict control of solution variables	Envirometrics Series S-364 Sulfur dioxide analyzer and many others
	P&CAM 163	Impinger-Titration	0.01-5 mg	Up to 100 min. at 1 l/min.		
	P&CAM 204	Molecular seive-Mass. Spec.	2-625 mg/m^3	Up to 500 min. at 0.2 l/min.		
	S 308	Bubbler-Titration	6.6-26.8 mg/m^3	Up to 90 min. at 1 l/min.		
	P&CAM 160 Adaptions	Passive Dosimeter Spectrophotometer	0.020-6 ppm	Up to 7 days	Field studies	DuPont Pro Tek™ Badge

(Continued)

Table 3-1. Continued

Substance	Method	Medium-Procedure	Range	Sampling Time	Research Needs	(Tubes or Direct-Reading) Instrument
6. CO_2	S 249	Gas Bag-GC	2270-10,000 ppm (500-15,000 ppm)	8 hr.		
7. CO	P&CAM 112	Gas Bag-IR	10-500 ppm	Min. to hours	Cannot store samples	General Electric, Interscan, Energetic Science, Others
8. Ammonia	S 347	Silica-Gel on specific electrode	17-68 mg/m^3			DuPont Pro Tek
	S 340	Bag-Electrochem.	24.7-115.4 ppm	Up to 70 min. at 0.05 l/min.		Drager Multi Gas Detector
	P&CAM 205	Midget Impinger-Colorimetric	20-135 ppm	Up to 15 min. at 1 l/min.		Wilks Miram-103 Portable Vapor Analyzer Second derivative UV adsorption spectrometer
	P&CAM 205 Adaption	Passive Dosimeter Spectrophotometer	0.05-60 ppm	Up to 7 days	Field Studies	DuPont Pro Tek™ Badge
	P&CAM 108 Adaption	Passive Dosimeter Spectrophotometer	0.02-12 ppm	Up to 7 days	Field Studies	DuPont Pro Tek™ Badge
9. HCl	S 246	Bubbler-Ion specific electrode	3.5-14 mg/m^3	Up to 15 min. at 1 l/min.		Bacharach Gas Hazard Ind. Bacharach Instrument Co.

(Continued)

Table 3-1. Continued

Substance	Method	Medium-Procedure	Range	Sampling Time	Research Needs	(Tubes or Direct-Reading) Instrument
10. Chlorine	P&CAM 115	Impinger-Ion specific electrode	0.1-1750 mg/m^3	Up to 80 min. at 2.5 l/min.		Bacharach Gas Hazard Ind. Bacharach Instrument Co.
	P&CAM 209	Bubbler-Colormetric	0.015-1.0	Up to 30 min. at 1 l/min.		CFA Model 555 Continuous Colorimetric Analyzer (Multiple Gases)
11. Ozone	S 8	Impinger-Colorimetric	0.1-0.4 mg/m^3	Up to 45 min. at 1 l/min.	Accuracy not established	Model 034 Ozone Recorder Ozone Research & Equip. Co.
12. NO$_2$	P&CAM 108	Bubbler-Colorimetric	0.01-10 g/l	Up to 30 min.		CEA Model 555 continuous colorimetric analyzer (multiple gases)
NO$_2$/NO	P&CAM 231	Solid Sorbent-Spectrophotometry	0.8-30 ppm	Up to 20 min. at 50 ml/min.	Accuracy not established	Energetic Science MDA-Monotoxx Second derivative UV absorption spectrometer
NO$_x$	See NO$_2$ P&CAM 108	Palmes Tube				
13. Formaldehyde	P&CAM 125	Impinger-Spectroph.	0.1 ppm-2.0 ppm	Up to 24 hrs.	Problems with sample storage	Bendix Gastec Hazard Detector System, National Environmental Instruments, Inc., CEA, Wilks-Miran
	P&CAM 235	Alumina-Spectroph.	0.4-5.2 mg/m^3	Up to 30 min. 200 ml/min.		
	ORNL/CPSC	Passive Membrane Spectroph.	2.0 ppb-5 ppm	Up to 10 hrs.	Field Studies	
	P&CAM 125 Adaption	Passive Dosimeter Spectrophotometer	0.02-6 ppm	Up to 7 days	Field Studies	DuPont Pro Tek$^{\text{TM}}$ Badge

(Continued)

Table 3-1. Continued

	Substance	Method*	Medium-Procedure	Range	Sampling Time	Research Needs	(Tubes or Direct-Reading) Instrument
14.	Total Fluoride/HF	P&CAM 117		0.05-475 mg/m^3	Up to 80 min. at 2.5 l/min.		
15.	Total & Particle Fluoride	P&CAM 212	Membrane Filter-Specific Ion	0.005-5 mg/m^3			CEA Model 555 Continuous Colorimetric Analyzer (Multiple Gases)
16.	Mercury & Cmpds.	P&CAM 175	Solid Sorbent-Atomic Abs.	0.001-1.0 g	10 min. up to 1 hr.		MSA Universal Tester Mine Safety Appliance Co.
17.	Trace Metals	P&CAM 173	Filter-Atomic Abs.	Varies			Columbia Scientific Portable XRF
18.	Lead & Cadmium	P&CAM 191	Membrane Filter-Anodic Strip Voltometry	0.0016-.01 mg/m^3 pb 0.00008-.01 mg/m^3 Cd	66.7 min.		MSA Universal Tester Mine Safety Appliances Co.
19.	Sulfate		Treated Filter/	0.1-10 mg/m^3	Up to 133 min.	Need to investigate	
		P&CAM 125	Passive Dosimeter Adaptive Spectroph.	0.02-6 ppm Up to 7 days	Field Studies		DuPont Pro-Tek™
	Sulfite SO_2	P&CAM 268	Ion chromatograph	0.1-10 mg/m^3 0.04-4 ppm 0.04-4 ppm	at 1.5 l/min.	Negative bias due to oxidation	
20.	PCl_3	P&CAM 305	Bubbler-Colorimetric	1.2-20 mg/m^3	120 min.		
21.	PCl_5	P&CAM 257	Filter/Bubbler-Colorimetric	0.55-2.0 mg/m^3	240 min.		

(Continued)

Table 3-1. Continued

	Substance	Method	Medium-Procedure	Range	Sampling Time	Research Needs	(Tubes or Direct-Reading) Instrument
22.	Organophosphorus Pesticides	P&CAM 21	Impinger/Filter-GC	Varies	Up to 4 hrs.		Sequential Pesticide Sample Model 88, Microchemical Specialties Co.
23.	Vinyl Chloride	P&CAM 178	Charcoal-GC	0.008-5.2 mg/m^3	Up to 100 min.		Bendix Gastec Hazard Detector National Environmental Instru., Inc.
24.	(incl. halog. hydroc.) Organic Solvents	P&CAM 127	Charcoal-GC	Varies	Up to 97 min.		Drager Multigas Detectors National Drager, Inc.
25.	Petroleum Distillates	S 380	Charcoal-GC	937-393 mg/m^3	Up to 20 min. at 0.2 l/min.		
26.	PNAs	P&CAM 183	Membrane-Filter-GC	2-1000 g/m^3	Up to 250 min. at 2.0 l/min.	Precision not determined	
		ORNL	Filter-Sorbent Fluoresence	1-1000 mg/m^3	Up to 8 hr.	In progress	
27.	Nitrosoamine	P&CAM 299	Tenax-GC	2-20 g/m^3	Up to 500 min. at 0.01 l/min	Research on nitrosoamines is continuing	
			Thermosorb/ Thermo-energy Analyze	10-1000 ppt	Up to 60 min. at 8 l/min.	Validation, automation and field testing	

(Continued)

Table 3-1. Concluded

	Substance	Method	Medium-Procedure	Range	Sampling Time	Research Needs	(Tubes or Direct-Reading) Instrument
28.	N Nitroso dimethyl amine	P&CAM 252	Tenax-GC	0.5 ppt-10 ppb	Varies		
29.	Radon & Radon daughters	Health Physics 23:738-789(1972) Thomas, J.W.	Use charcoal if want Radon specifically p. A-8 Air Sampl. Instr. 5th Ed. (1978)		5 min.		
30.	Freon 114 12	S 108 S 111	Charcoal-GC Charcoal-GC	3500-14,100 mg/m^3 2940-10,500 mg/m^3	Up to 300 min. at 0.01 l/min. Up to 300 min. at 0.01 l/min.	Probability of loss if back-up tubes exceed 12 mg. Probability of sample loss exist using tube	11-654 Portable Flame Ioniz. Meter, Scott Aviation-Davies Instr.

3.2 QUALITY ASSURANCE

Existing, modified, and new instruments will be required for quantifying the levels of specific indoor air contaminants and for evaluating indoor air quality. In order that the data obtained in monitoring health-risk contaminants in nonindustrial indoor environments (including residences, schools, hospitals, restaurants, entertainment arenas) be accurate, reliable and intercomparable, a number of criteria are essential. The critical components of any valid monitoring study require at minimum that: (1) the instruments used are fully evaluated (for specificity, useful dynamic range of detection, uncertainties associated with the measurements, sensitivity, stability, interferences (physical and chemical), field use, and economy; (2) the instruments used are calibrated with appropriate and reliable standards that assure performance reliability prior to, during, and following monitoring exercises; and (3) quality assurance and quality control protocols are developed and followed that assure the quality of the data collected.

3.2.1 Evaluation of Instruments

Preevaluation of instruments employed in indoor air quality assessments is critical. The use of unevaluated instruments often results in data of unknown reliability. Further, the assumption of reliability for unevaluated instruments can lead to misleading and erroneous results. At best, since the resultant data quality for unevaluated systems has an accuracy certainty, one is left with interpretations based on temporal trends, the precise quantification of which may be unclear. Preevaluation of indoor air quality instruments requires laboratory confirmation of measurement range, measurement accuracy, and uncertainty associated with measurements over the established range, assessment of interferences that might plausibly occur in field monitoring studies, and the performance stability of the instruments selected. A fully-evaluated instrument should also be tested for air movement effects on measurements associated with the indoor environments. Having evaluated instruments in place, the quality of the data may be assured by the use of meaningful protocols involving the use of standards and quality assurance mechanisms. These are briefly discussed below.

3.2.2 Field and Laboratory Standards

Field and laboratory standards are intended to represent standard materials used for the calibration of the instruments selected for indoor air quality measurements. Laboratory standards are required to precalibrate instruments prior to use in field monitoring studies. Field standards are similar in nature to laboratory calibration standards, with the exception that they need to be readily portable in nature for field calibration purposes range of response of the instruments used for measurement. The full composition of the standard materials should be known, covering both the concentration of the standard and its true concentration uncertainty, and the presence and concentration of impurities. Finally, the stability of the standards must be determined to assure their reliable use over a useful lifetime. A number of gaseous standards identified in the Indoor Air Quality Research Strategy are available as Standard Reference Materials (SRMs) from the National Bureau of Standrds (NBS). These include carbon dioxide, carbon monoxide, nitrogen dioxide, nitric oxide, and sulfur dioxide. Other relevant standards available or under development by NBS include asbestos, halogenated hydrocarbons (freons, and other low molecular weight organics determined by EPA to have associated health risks), lead, sulfate, nitrate, tetrachloroethylene, air particulates, trace elements, and vinyl chloride. Some of these exist as current SRMs; some require further development. A number of additional standards will likewise be required for indoor air quality programs.

3.2.3 Quality Assurance Programs

Allowing that evaluated instruments and reliable standards for instrument laboratory and field calibrations are available, the success of indoor air quality measurements will rely on the establishment of useful programs to provide a continuing quality assurance to indoor air quality measurements. These types of programs have traditionally been established at NBS for numerous other research activities involving measurement quality assurance. For meaningful quality assurance and quality control for indoor air quality measurements, it is imperative that protocols be developed for (1) the establishment of a Measurement Assurance Program (MAP), (2) calibration facilities, and (3) laboratory proficiency evaluation for laboratories involved in field measurements. It is recommended that NBS, with its traditional expertise in the establishment and conduct of MAPs and calibration facilities, take the lead and be intimately involved in the development and provision of Quality Assurance Programs and protocols for the indoor air quality research program in collaboration with other Agencies involved in the indoor air quality arena. It is anticipated that the activities in this domain of quality assurance/quality control will and should include (a) round-robin analyses; (b) evaluation of available instruments in collaboration with other NBS activities; (c) statistics; and (d) interlaboratory proficiency testing.

3.3 INSTRUMENTATION FOR MEASURING RADON, THORON AND THEIR PROGENY IN BUILDINGS

3.3.1 State of the Art

Like other indoor air pollutants, radon (both radon-222, and radon-220, "thoron") concentrations vary greatly with time and location. For this reason the inference of long-term radon exposure requires that measured concentrations should be averaged over as long a period as possible to eliminate short-term perturbations and should include as many measurements as are reasonably possible. The techniques for monitoring indoor radon-222 and its progeny are sufficiently developed to meet most requirements. Choice of the instrument and method depends on the levels to be measured, length of exposure, and the accuracy required. Of course instrument availability and cost must be considered.

Considerably less attention has been paid to techniques for measuring thoron and thoron progeny than is the case with radon-222. However, the rather sparse data available indicate that there are situations where indoor thoron progeny working levels can be a significant fraction of, and even exceed, the radon progeny levels. Thus, assessments of the thoron contribution to total indoor radon exposure should become an integral part of field studies and associated instrument development.

Tables 3-2 through 3-5 show the most commonly used instruments and methods for radon and thoron and radon progeny measurements in the field. For indoor measurements, it is advantageous to use continuous or integrating methods that provide direct estimates of the average radon and radon progeny exposure. Grab sampling programs would have to be quite extensive to provide comparable information.

For measuring radon, integrating passive detectors such as nuclear track detectors are the simplest to deploy in houses, but require lengthy periods of exposure (minimum 1 month) for adequate signal registration. Fortunately, this is often desirable for the determination of mean exposure levels. Passive integrating monitors using ion collection are more sensitive, and exposures of a few hours to several days' duration can be attained at higher cost. In cases where special studies are needed, continuous radon monitors using the flow-through scintillation flask can be used at a limited number of locations.

For measuring working level, time-integrating, or continuous monitors can be used by collecting radon progeny on filters. Their radioactivity is detected either by thermoluminescence materials or by alpha counters. Monitors of both types can be assembled from commercially available components.

For calculation of lung dose to building occupants, information on radioactive particle size distribution, unattached fraction and respiratory deposition is desirable. Particle size distributions of radon daughters can be measured with different types of diffusion batteries; their size and flow-rate depend on the radioactivity levels to be measured. Prototype diffusion batteries have been used successfully, but none are available commercially. Particle size measurements are difficult to make, requiring complex instruments for limited data. Fortunately, the limited measurements of the particle size of radon progeny have ranged between 0.10 μm and 0.15 μm in diameter, a somewhat narrow range, and perhaps particle size measurements might be made in only a small number of homes.

The situation is more complicated with respect to the measurement of the degree of attachment of indoor radon progeny to atmospheric particulates. This parameter is important because it influences the equilibrium ratios of radon progeny in air and the degree and location of lung deposition. Moreover, it depends on aerosol concentration and size distribution, and the surfaces to which both aerosols and atoms can attach. Data on these factors

Table 3-2. Instruments and Methods for Measuring Radon in Air

Instrument and Method	Application	Principle of Operation	Sensitivity*	Reference
Scintillation flask	**Grab or continuous sampling**	Scintillation alpha count	**< .01 - 1.0 pCi/ℓ**	1, 2
Two filter	**Grab or continuous sampling**	Decay of radon and collection of progeny products on second filter; alpha count	**0.01 - 5 pCi/ℓ**	3, 4
Pulse ionization	**Grab (laboratory only)**	Sample transferred into ion chamber; pulse ion count	**< 0.05 pCi/ℓ**	5
Track etch	**Time integrating**	Alpha sensitive films register tracks when etched in NaOH	**0.2 - 1.0 pCi-month/ℓ**	6, 7
Passive	**Continuous**	Radon diffusion into sensitive volume. Po-218 collected on scintillation counter electrostatically	0.5 pCi/ℓ	8
Plastic bag	**Time integrating**	Collection of ambient air in bag. Transfer in scintillation flask; alpha count	**< 0.1 pCi/ℓ**	9
Passive monitor	**Time integrating**	Radon diffusion into sensitive volume. Po-218 collection on TLD electrostatically	0.03-0.3 pCi/ℓ	10
Passive monitor	**Continuous**	Radon diffusion into sensitive volume. Removal of radon daughters by electret. Count alpha particles from radon only	0.1 pCi/ℓ	11

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*The precision of the measurements is about ±20%

Table 3-3. Instruments and Methods for Measuring Radon Progeny in Air

Instrument and Method	Application	Principle of Operation	Sensitivity*	Reference
Kusnetz and Rolle	Grab sample for working level only	Collect sample on filter; alpha count	0.0005 WL**	12, 13
Tsivoglou and modifications	Grab sample for individual radon progeny and working level	Collect sample on filter; alpha count	0.1 pCi/ℓ each of RaA, RaB and RaC - 0.0005 WL	14, 15, 16 and 17
Alpha spectrometry	Grab sample for individual radon progeny and working level	Collect sample on filter, count in alpha spectrometer	0.5 pCi/ℓ each of RaA, RaB and RaC - 0.002 WL	18, 19
Instant working level monitor	Grab sample for individual radon progeny and working level	Automatic sample collection, alpha or alpha and beta count	0.1-1.0 pCi/ℓ each of RaA, RaB and RaC - 0.001-0.01 WL	20
Working level monitor	Time integrating radon progeny concentration	Collect sample on filter (1 - 2 weeks). Detect with thermoluminescent material	0.0005 WL in a week	21, 22, 23
Working level monitor	Time integrating or continuous radon progeny concentration	Collect sample on filter continuously. Detect alpha radioactivity with silicon surface barrier detector.	0.00004 WL in a week	24

*The precision of the measurements is about ±20%.

**1 WL (working level) is the concentration of radon progeny in 1 ℓ of air that will release 1.3 x 10^5 MeV of alpha energy upon complete decay through Po-214.

Table 3-4. Instruments and Methods for Measuring Thoron Working Level in Air

Instrument and Method	Application	Principle of Operation	Sensitivity*	Reference
Strong and Duggan	Grab sample for working level	Collect sample on filter; alpha count in several successive periods	0.001 WL	25
Ogden	2-3 hour sample for working level	Collect sample on filter; alpha count for two successive periods	0.001 WL	26, 27
Alpha spectrometry	Grab sample for individual radon and thoron progeny and working levels	Collect sample on filter; count in 3-channel alpha spectrometer. Microprocessor controlled	0.005 WL	28

*The precision of the measurements is about ±25%.

Table 3-5. Radon Sources and Transport

Type of Measurement	Instrument and Method*	Principle of Operation	Reference
In Situ			
Radon exhalation rates from materials	Charcoal canister	Radon adsorption on activated charcoal; count in NaI (Tl) analyser for Bi-214 and Pb-214.	29
	Accumulation chamber	Transfer radon to scintillation flask; alpha count.	30, 31
Radium-226 content	Gamma-ray spectrometry	Measure primary gamma ray flux from Bi-214 and Pb-214 with high resolution Ge (Li) detector.	32
Laboratory			
Emanation power	Emanation chamber	Seal material in chamber; gamma count. Open chamber, aerate sample and recount.	33, 34
Radon in soil gas	Tube in ground	Transfer soil gas sample into scintillation flask; alpha count.	30
	Passive CARD	Radon progeny plate-out on both sides of alphaCARD; count both sides in two solid state silicon detectors.	35
Radon in water	Liquid scintillation vial	Water sample mixed with scintillation fluid; count in liquid sctinillation counter.	36
	Modified Marinelli beaker	Count sample in NaI (Tl) analyser for Bi-214 and Pb-214.	37

*The precision of most of these methods is better than 20%.

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are too sparse to permit any generalizations, due in part to the lack of readily-available instrumentation for particle size and unattached fraction measurements. More research in this area is clearly needed.

For diagnostic purposes, sources of radon and radon progeny input into the indoor environment are important, necessitating measurements of radon exhalation from building surfaces and from the soil, infiltraton through openings in the foundation, and radon concentration in water supplies. Table 3-5 indicates some existing techniques. Radon exhalation can be readily measured. Rapid measurements use the accumulation technique (0.5 - 2 hours), and integrated measurements up to 3 days can be made with charcoal canisters. Radon in water supplied to residences should be measured to ascertain its input on the indoor radon levels. Radon in domestic water supplied from surface waters need not be measured at all.

The air exchange rate inside homes is another measurement of interest since air concentration is a function of ventilation rate as well as radon input rate. There is a need for standardizaton of procedures among the numerous techniques to facilitate interpretation of the rate of air exchange; ASTM's standard should be taken into consideration by researchers.

The state of the art can be summarized as follows:

1. Much development work has been done over the last 20 years in response to problems such as uranium mine exposure, releases from uranium tailings piles, and high indoor exposures in structures built on reclaimed phosphate lands.

2. Adequate, if not optimal, techniques exist and are being applied in research studies of radon and radon progeny concentrations in indoor air, their dependence on ventilation rate, heating and cooling system operating parameters, meteorological variables and living habits, the particulate size distribution of attached radon progeny, and the degree of attachment of such progeny. However, improvements are being made in many of these techniques to make larger-scale field studies more practical.

3. Passive integrators of radon gas exposure over periods of weeks or months have recently been developed and are being evaluated. They are likely to be adequate for large-scale surveys. There is a strong need for analogous integraters of radon progeny exposure.

4. Many of the techniques suitable for measurements of radon-222 can be applied to radon-220 ("thoron"), but little data exist on exposure to thoron and its progeny or on how thoron contributes to "radon" readings.

5. Some progress has been made in quantifying and understanding the uncertainties associated with various types of radon measurement. Considerably more effort is required to adequately define measurement techniques and protocols for general use, provide standard calibration facilities and sources, and carry out detailed evaluations of various instruments and measurement methodologies.

3.3.2 Research Needs

Given the monitoring instruments on hand, the following instrumentation needs should be addressed:

1. A small and inexpensive passive radon progeny monitor, suitable for large-scale surveys of integrated exposure
2. Improved practical detectors for continuous radon monitoring, suitable for diagnostic studies of radon variations inside buildings
3. Further development of instrumentation for measurements of particle size and unattached fraction on a routine basis
4. Development of improved methods and appropriate instrumentation for studies of radon transport through the soil and building foundations
5. Development of improved methods for thoron and thoron progeny measurements
6. Evaluation of existing methods of radon and radon progeny measurement through intercalibration and intercomparison experiments, and the development of common measurement protocols and methodologies
7. Development of calibration facilities and protocols, and transfer standards relatable to national standards, particularly for radon progeny
8. Establishment of ongoing measurement assurance mechanisms that incorporate (6) and (7) above.

The priorities to be associated with some of these needs are somewhat dependent on the identified monitoring needs. For example, there are quite significant differences between the instrumentation needs for large-scale radon studies and those for detailed diagnostic studies in individual structures. However, it should be emphasized that items (6)-(8) above are outstanding needs in any case. Cooperation among the laboratories with capabilities in these areas to respond to those needs is strongly encouraged.

While considerable progress has been made, particularly in the past year, in the consideration of the special problems associated with both large-scale surveys and indepth studies of radon in structures, much more work needs to be done to develop practical and commercializable detectors and optimum protocols for field measurements. Informal intercomparisons of instruments and methods have taken place, but more formal programs are much needed. These concerns will continue to be addressed in the activities of the Interagency Research Group and of the Indoor Radon Task Force of the U.S. Radiation Policy Council.

A general need, not specific to radon, is the development of multi-pollutant monitoring packages containing small, inexpensive integrating detectors for radon and key chemical pollutants that could be left unattended for long periods to provide measurements of integrated concentrations. Such packages would provide a practical means of obtaining a data base on typical ranges and trends of pollutant exposure in U.S. buildings. Such a development should be an important goal of interagency research programs.

3.4 AEROSOL INSTRUMENTATION

3.4.1 Summary on the State of the Art

Several instruments and instrumentation methods for aerosol monitoring are presently available. As applied to indoor air quality characterizaton, these instruments can be classified into two general categories: (1) personal samplers and (2) area samplers and monitors. Personal samplers are typically filter collection-pump combinations with or without size preselectors, and are used for gravimetric (i.e., mass concentration) and/or chemical characterization of the aerosol to which individuals are exposed over periods of the order of hours or days.

Area samplers are usually filter collectors, with or without size preselectors; cascade impactors; electrostatic precipitator samplers, etc. Area monitors are available for real-time, or continual measurement of aerosol concentration and/or particle size distribution. Real-time, or quasi real-time instruments (i.e., with characteristic response time of the order of seconds or minutes) most commonly available and applicable to indoor aerosol monitoring and measurement are based on the following sensing principles: (a) beta radiation attenuation, (b) piezoelectric resonance, (c) light scattering, (d) electrical mobility, and (e) condensation nuclei counting. Beta attenuation and piezolectric resonance are used for mass concentration determinations. Light scattering is applied to either equivalent mass concentration or particle count and size measurements, and in combination with an oscillating electric field, light scattering has been applied to the selective detection and sizing of fibrous-shaped particles (Fibrous Aerosol Monitor). Electrical mobility and condensation nuclei detection are methods applied to particle counting and sizing.

Several of the above mentioned techniques have been incorporated in instruments that are compact, self-contained (i.e., battery operated) and portable. Table 3-6 briefly summarizes many aerosol sizing, calibration and measuring instruments. Appendix D outlines how to select portable aerosol instruments and provides more detailed information on selected instruments.

Aerosol calibration methodology is available for laboratory purposes. There are, however, no simple and straightforward techniques for field calibration, except secondary methods to check the operational performance of real-time monitors. Table 3-7 is a selected list of common aerosol generators.

Most aerosol monitors require active sampling from the surrounding environment, and exhibit some degree of particle size discrimination or bias. The use of so-called "total suspended particulate" samplers or monitors ought to be discouraged; specific and well controlled particle size limitations; i.e., by the use of size preselectors and/or properly designed inlet configurations, should be required to prevent errors and inconsistencies associated with "open endedness" at the large particle end.

Accuracy of presently existing instruments and techniques is often difficult to define because of the inherent inaccuracy and ambiguity of many of the reference methods. In general, however, intermethod comparisons usually yield agreements within a factor of two. Repeatability of a given device, under similar monitoring conditions, is frequently within 10 or 20 percent, and occasionally much better.

Problems of measurement and monitoring of aerosols are inherently more complicated than those of gases. Heterogeneity of particle size, composition and shape are idiosyncratic of most adventitious aerosols creating difficulties in representative sampling, detection, and characterization. Thus, the concentration range of specific instruments and techniques exhibits complex dependencies on those additional parameters. Number concentration sensitive techniques (e.g., electrical mobility, condensation nuclei counting and light scattering particle counting) respond preferentially to or are dominated by, the small particle fraction of an aerosol, whereas mass sensing devices emphasize the larger particle fraction whose mass predominates over that contributed by smaller particles. Inertial, optical, electrical, and chemical properties of aerosols, as well as their physical state, affect the accuracy of their measurement, and consequently no single technique exists at present capable of covering their broad range of variability, and much less of providing their full characterization.

By combining several techniques it is possible, however, to cover the wide range of concentrations and particle sizes of interest that have to be considered when monitoring such disparate environments as emission sources and ambient air. The range of aerosol particle concentrations in indoor environments fluctuates between a few micrograms per cubic meter up to peaks of the order of tens of milligrams per cubic meter. The size range of interest, especially when health effects are the governing criteria, is the so called respirable fraction, i.e., particles whose equivalent aerodynamic diameter

Table 3.6. Near Real Time Aerosol Particle Sizing, Calibration, and Concentration Measuring Instruments

Size Distribution	Manufacturer Model	Particle Diameter Range	Concentration Range	Time for 1 Management	Sample Flow	Comments
Diffusion battery and condensation nuclear counter	TSI 3040, 3020, & 3042	0.005-0.3 µm	$0-10^6/cm^3$	240 sec	4 L/min	All sizing instruments required under methods development and refined development of characterization methods. Data reduction needs improvement.
Electrical mobility analyzer	TSI 3030	0.005-1.0 µm	$10^1-10^7/cm^3$	40 sec	4 L/min	Used extensively for other ambient aerosol.
Optical particle counter	Roger 218	0.5-10 µm	$0-400/cm^3$	1 or 10 min	$0.01\ ft^3/min$	Requires dilution for indoor ambient aerosol.
	Roger 225	0.3-10 µm	$0-4000/cm^3$	1 or 10 min	0.01 or $0.1\ ft^3/min$	Requires dilution for indoor ambient aerosol.
	Roger 226	0.15-10 µm	$0-1000/cm^3$	5 sec-15 hrs	$5\ cm^3/sec$	Requires dilution for indoor ambient aerosol.
	Roger 245	0.5-10 µm	$0-10/cm^3$	1 or 10 min	$1\ ft^3/min$	Requires dilution for indoor ambient aerosol.
	Climet CI-208	0.3-10 µm	$0-400/cm^3$	1 or 4 min	$0.25\ ft^3/min$	Requires dilution for indoor ambient aerosol.
	Climet CI-225	0.3-10 µm	$0-400/cm^3$	1 min	$0.25\ ft^3/min$	Requires dilution for indoor ambient aerosol.
	Climet CI-250	0.5-10 µm	$0-400/cm^3$	1 min	$1.0\ ft^3/hr$	Requires dilution for indoor ambient aerosol.
	PMS ASAS-300	0.15-3 µm	$0-10^5/cm^3$	1 sec-16 min	$0.1\ cm^3/sec$	May require dilution for indoor ambient aerosol.
	PMS CSASP-100	0.3-10 µm	$0-10^5/cm^3$	1 sec-16 min	$0.1\ cm^3/sec$	May require dilution for indoor ambient aerosol.
	PMS IAS-100	0.3-5 µm	$0-1000/cm^3$	1 sec-16 min	$0.1\ cm^3/sec$	May require dilution for indoor ambient aerosol.
	Met One 209	0.5-10 µm	$0-1000/cm^3$	6-600 sec	$1\ ft^3/min$	Requires dilution for indoor ambient aerosol.
Piezoelectric cascade impactor	Briefing document	0.15-10 µm	$100-20{,}000\ \mu g/m^3$	2 sec	0.24 l/min	Requires manual cleaning of 10 sensors for each measurement.
	Conference document	0.15-10 µm	$100-20{,}000\ \mu g/m^3$	2 sec	0.24 l/min	Requires manual cleaning of 10 sensors for each measurement.
Condensation nuclei counter	BOI-Pollak	0.005-1.0 µm	$10-5\times10^5/cm^3$	1 min	Dichotomous, manual	Expansion chamber, water condensation.
	E/1 Rkh 200	0.005-1.0 µm	$100-10^6/cm^3$	1 sec	1.8-4.2 l/min	Expansion chamber, water condensation.
	Gardner CN	0.005-1.0 µm	$200-10^6/cm^3$	1 sec	Dichotomous, Manual	Expansion chamber, water condensation, battery power.
	GE CN-2	0.005-1.0 µm	$10-10^6/cm^3$	1 sec	5.1 l/min	Expansion chamber, water condensation
	TSI 3020	0.005-1.0 µm	$0.01-10^6/cm^3$	1 sec	0.3 l/min	Continuous flow, butanol condensation
Fiberous aerosol monitor	GCA FAM-1	10-300 µm (k-myth)	$0.0001-30/cm^3$		2 L/min	
Mass Concentration						
Piezoelectric microbalance	TSI 3500	0.01-10 µm	$5-10{,}000\ \mu g/m^3$	24 or 120 sec	1 l/min	Direct mass sensor, direct recording, manual operation, battery, 4 kg, electrostatic collection.
	TSI 5000	0.01-10 µm	$5-10{,}000\ \mu g/m^3$	1-9999 sec	1 L/min	Direct mass sensor, direct recording, manual operation, electrostatic collection.
Beta radiation attenuation	GCA RDM-101	0.8-10 µm	$200-20{,}000\ \mu g/m^3$	1 or 4 min	2 l/min	Direct mass sensor, direct recording, manual operation, battery, 4 kg, impaction collection.
	GCA RDM-201	0.01-10 µm	$500-500{,}000\ \mu g/m^3$	1-240 min	2 l/min	Direct mass sensor, direct recording, manual operation, battery, 4 kg, impaction collection.
	GCA RDM-301	0.8-10 µm	$200-75{,}000\ \mu g/m^3$	0.3-99 min	2 L/min	Direct mass sensor, direct recording, manual operation, battery, 15 kg, impactor collector, printer.
	GCA APM-1	0.01-10 µm	$2-100{,}000\ \mu g/m^3$	2-998 min	9 l/min	Direct mass sensor, direct recording, manual operation, battery, 15 kg, impactor collector, printer.
Light scattering photometry	GCA RAM-1	0.3-15 µm	$2-200{,}000\ \mu g/m^3$	1 sec	2 L/min	Requires calibration for mass concentration, battery, 5 kg.
	Leitz TM-Digitel	0.3-100 µm	$10-100{,}000\ \mu g/m^3$	1 sec	No sampling	Requires calibration for mass concentration, battery, 4 kg.
	Sibata P-5	0.3-15 µm	$10-100{,}000\ \mu g/m^3$	1 sec	Unknown	Requires calibration for mass concentration, battery, 4 kg.
	Simslin 1900	0.3-15 µm	$10-100{,}000\ \mu g/m^3$	1 sec	0.625 L/min	Requires calibration for mass concentration, battery, 8 kg.
	TSI 5150	0.3-15 µm	$10-100{,}000\ \mu g/m^3$	1 sec	4 L/min	Requires calibration for mass concentration, battery, 4 kg.

Table 3-7. Standard Aerosol Generators for Calibration

Standard Aerosol	Manufacturer and Model	Particle Diameter	Production Rate	Geometric Standard Deviation	Comments
New uniform size: Vibrating orifice generator	TSI 3050	0.5-100 µm	Varies with size: Large size: 1×10^3/sec Small size: 5×10^3/sec	< 1.05	Generates droplets which can be dried
Nebulizer with polystyrene Latex (PS[illegible])	TSI 3076	0.09-5 µm	Varies with size	< 1.05	
	Rayco 256	0.09-5 µm	Varies with size	< 1.05	
	Climet CI-295	0.09-5 µm	Varies with size	< 1.05	
	BGI	0.09-5 µm	Varies with size	< 1.05	
Electrostatic classification	TSI 3071 & 3076	0.007-1 µm	Varies with size and aerosol	< 1.08	Can separate on nearly any aerosol material
Spinning disk	BGI	1-30 µm	Varies with size	< 1.10	Generates droplets which can be dried
Other liquid aerosol generators: Nebulizer, atomizer		0.005-5 µm	Varies with size and material	1.8-2.2	Generates droplets which may be dried
DOP filter test system		0.05-5 µm	Varies with size and material	1.8-2.2	Generates droplets containing oil which may be dried
Dry [illegible] generators: Fluidized bed	TSI 3400	0.1-15 µm	Varies with size and material		Varies with any powder
	[illegible]	0.1-15 µm	Varies with size and material		Varies with any powder
	GCA AG-1	0.1-15 µm	Varies with size and material		Varies with any powder
Wright dust feeder	BGI	0.1-15 µm	Varies with size and material		Varies with any powder

is less than about 5 μm (the actual limit varies with each particular convention). Existing portable instruments using beta attenuation, piezoelectric resonance and light scattering quite adequately cover the particle concentration and size ranges mentioned above.

In summary, extant instruments, especially those that are portable, are capable of providing the physical characterization of indoor aerosols; i.e., concentration, size, and for special cases, shape. No compact, self-contained monitors are available for the direct chemical characterization of aerosols.

3.4.2 Standard Methods and Criteria for Acceptance of New Developments

Most of the standard or reference methods for the assessment of aerosols are based on gravimetry or on microscopy of samples collected on filters (e.g., EPA Hi-Vol method, NIOSH asbestos fiber counting method, etc.). These methods are, in most cases, nonreal time, tedious, labor intensive, and provide delayed results. The majority of these legislated methods do not provide for an acceptance mechanism for equivalent and/or alternate techniques. This situation tends to discourage the development of new, more advanced measurement technology because general use of such novel instrumentation is in conflict with existing regulations.

Although the stipulation of standard reference methods is mandatory and indispensable, regulatory mechanisms permitting the determination of equivalence and/or the acceptance of alternate approaches must be implemented in order to promote the technical evolution of monitoring instrumentation, especially in the field of aerosol characterization.

It is recommended that an official, perhaps governmental, testing organization be assigned or recreated to test, evaluate, and report on newly developed monitoring instrumentation. At present this evaluation procedure is, at best, unreliable, and, at worst, inexistent. Even instrumentation developed under Government sponsorship is seldom evaluated objectively and reported on in a disinterested manner. Usually the only published technical documents are those issued by the contractor responsible for the development itself, who is hardly to be considered an objective reporter.

Instrument acceptability, equivalence, performance limitations, and range of applicability should be established on the basis of a clearly stipulated and generally accepted methodology, performed by a competent and disinterested scientific group.

The acceptance mechanism, coupled with a clear definition of the potential market and specific instrumentation needs to carry out a wide ranging monitoring program, are important preconditions to justify the risks and expenses to be incurred by industry associated with the development of new instrumentation.

As to developments sponsored by Government Agencies, a careful review and revision of the existing patent laws is suggested. The abrogation of patent rights by industry of inventions resulting from, or evolved within, such contractual activities tend to discourage such collaborative efforts and stifle inventiveness. Government contracts to industry for the development of advanced and novel monitoring instrumentation should permit a continuing effort, in a manner similar to government grants to research and academic institutions, such that well planned developments can be executed without the usual overriding requirement for the immediate delivery of hardware, at the expense of careful evaluation of such novel approaches.

3.4.3 Research Needs

Although a complete definition of research needs in the area of aerosol instrumentation can only be established by means of appropriate input from the corresponding monitoring and health effects subgroups, several specific directions can, however, be identified immediately, even in the absence of such inputs.

Presently existing instrumentation should be applied to the immediate assessment of indoor conditions, and to determine the shortcomings of such instrumentation in order to obtain criteria for further development needs. Questions such as required particle size resolution (if any are needed beyond respirable segregation), area monitoring vs. personal monitoring, etc. should be addressed. It was realized that the ideal instrument to characterize indoor aerosols should be capable of real-time measurement of the chemical composition and concentration as functions of particle size and shape. This desideratum does not exist at present and may not be reliable in practice.

Specific feasible R&D aerosol instrumentation needs that can be identified at this juncture are discussed in the following paragraphs.

3.4.3.1 Personal Exposure Monitoring Instrumentation

This is an extremely important instrumentation category. Presently available devices to assess personal exposure are limited to pump-filter samplers. The need exists for a personal monitor capable of both direct real-time readout as well as of integrated or averaged measurements. A high degree of miniaturization is required to provide an unobtrusive, wearable monitor. Although, at present, a government funded (NIOSH-BOM) program for such development is underway, the funding level available for that overall project appears to be insufficient and should be increased accordingly.

3.4.3.2 Real-Time Aerodynamic Particle Size Analysis

Although the specific particle sizing requirements have not been established in this context, it appears that detailed size information of the indoor environment is necessary to characterize the various contributors to indoor aerosol pollution and to provide guidelines for the design of routine monitoring instrumentation. Private industry funds are presently being expended to develop such instrumentation, but government support would, most probably, accelerate and facilitate such efforts.

3.4.3.3 Integrated Monitoring Package for Field Surveys

This development is not unique to aerosol measurements, but was deemed to be an indispensable tool for the assessment and characterization of indoor environments. This integrated monitoring package would consist of a carefully designed back-pack, or similar configuration, easily transported-carried, containing an array of air pollution sensors, and a miniaturized data recording-acquisition module. A common battery power source would be used to energize this monitoring system. It would be used for walk-through measurements or, alternatively, could be used as an integrated area, multi-pollutant monitoring station. Specific pollutants to be sensed would include organic gaseous contaminants. The monitoring package would be built in a modular configuration, each of the pollutant species being sensed by an independent detection unit. Data recording (e.g., cassette recorder, bubble memory, etc.) would be common, as well as would the power source and the sampling flow subsystem (this latter subsystem may be, however, separate for specific sensors, if deemed preferable). Real-time readout for each pollutant may be available in order to identify specific problem areas. Within this project, miniaturization and redesign of existing pollutant sensors would be required, in addition to the development of the overall package.

3.4.3.4 Sampling Methodology for Chemical and Biological Analysis of Aerosols

The immediately available methodology for the chemical and/or biological characterization of indoor environment aerosols will remain restricted to a two-step procedure: field sampling on a suitable medium, followed by laboratory analysis of the collected sample. This nonreal-time approach is the only one presently applied for multicomponent characterization of aerosol particles, and is expected to remain so in the immediate future. Appropriate particle sampling and collection methodology should be established in order to ensure representative and meaningful characterization of indoor aerosols.

Sampling and collection techniques, sample storage, transport and conditioning procedures, and analysis methodology must be defined and standardized in order to permit meaningful data intercomparison.

3.4.3.5 Miniaturization of Fibrous Aerosol Monitor

As part of the overall sensor miniaturization and redesign effort discussed within project 3.4.3.3 (integrated monitoring package) there is the specific need for miniaturization of the presently available GCA Fibrous Aerosol Monitor. This instrument would be uniquely suited for walk-through indoor air pollution characterizations. The presently existing device is too large for integration into the proposed portable multipollutant monitoring package.

3.4.3.6 Data Telemetry-Positional Transmission System

As a complement to such monitoring instruments as the personal exposure monitor and the integrated monitoring package mentioned above, the need exists for a miniaturized data telemetry and positional sensor radio system designed to permit time and motion studies of the indoor environment. Real-time definition and transmission of the location of an individual wearing a personal monitor or the integrated monitoring package is required to correlate concentration level information with specific indoor locations and activities.

3.4.3.7 Instrumentation for Real-Time Chemical Characterization of Aerosols

This research activity must be considered as a long-term project and should be planned as such. Specific chemical species of interest must be identified and carefully prioritized in order to provide reasonable bounds to this overall problem. The extremely large number of elements and compounds that constitute indoor airborne particles dictate such a careful selection before any instrumentation needs can be established. Sensing methodology for the selected chemical species must then be developed, modified, miniaturized, etc. Instrumentation complexity tradeoff between multicomponent and single-component sensing must be made. It is expected that significant advances with respect to present state-of-the-art will be required within this overall research program.

3.4.3.8 Development of Aerosol Standards for Validation and Calibration

Aerosol standards for laboratory and, possibly, field calibration of instrumentation have to be established in order to ensure comparability and standardization of methods and controlled and reproducible results. Generation of monodisperse as well as polydisperse aerosols will be required to calibrate, validate, and check the operation of monitoring instrumentation. Special generation facilities such as required for the calibration of the fibrous aerosol monitor will be required, as well.

3.5 ORGANIC POLLUTANTS

3.5.1 State of the Art and Research Needs

The task group concentrated on known problems of:

1. Aldehydes
2. Nitrosamines
3. Pesticides including chlordane
4. PCBs
5. PNAs.

The specifics of the development of suitable protocols and validation studies before extensive field studies can be undertaken need developing. The protocol outlined in NIOSH publication DHHS (NIOSH) No. 80-133, "Development and Validation of Methods for Sampling and Analysis of Workplace Toxic Substances," is an excellent beginning. This protocol should be modified to:

- Include lower concentrations and cover a wider range of concentrations
- Include the concept of diffusional type samplers
- Include field validation
- Include the concept of personal direct-reading instruments.

3.5.1 Aldehydes/Formaldehyde

NIOSH-SRI International developed and validated a bubbler sampling method. The analysis can be performed by either HPLC with UV detector or polarography. These methods are slow and do not lend themselves to large numbers of samples.

There are a number of laboratories actively involved in methods development for formaldehyde. At the Oak Ridge National Laboratory several approaches are in different stages of development. These include either active or diffusional collection of the formaldehyde on molecular sieve and traditional chemical analysis. ORNL has modified a CEA formaldehyde monitor to extend the range from the 0.5 ppm level to the 0.01 ppm level. The program needs laboratory and field evaluation and validation of the instrument.

The DuPont Company is developing a diffusional monitor, based on sodium bisulfate. The detection limit for an 8-hour sample is 250 ppb. The performance of the system seems to meet the NIOSH criteria outlined in its publication 80-133.

3.5.2 Nitrosamines

There are several known and proven methods for detection and measurement of low levels of nitrosamines:

- Use of activated charcoal traps together with portable pumps with subsequent analysis by capillary GC or GC/MS
- Use of Tenax GC sorbent traps with portable pumps and analysis by capillary column GC/MS analysis (Pelazarri technique)
- Use of cryogenic traps
- Use of potassium hydroxide

- Use of Thermosorb traps with subsequent analysis by Thermal Energy Analyzer (TEA).

All of the traps listed above display artifacts in the measurement of nitrosamines and other volatile organic compounds. The reader is referred to Pellizzari's publications for a more detailed description of these limitations.

When the Thermosorb is used with a portable pump drawing 8-1/min, the sensitivity which can be attained when analyzing with the TEA is 10-100 ppt. Using this same combination of trap and instrument, Thermo Electron has measured nitrosamines in the following places:

Kitchen of residence	0.5 $\mu g/m^3$
New care	0.6 - 2.0 $\mu g/m^3$
Rocket factory	5.0 - 10 $\mu g/m^3$
Tire factory	200 $\mu g/m^3$
Ambient level (general)	1 ng/m^3

Analysis for nitrosames collected by Thermosorb trap can be alternatively carried out using the Hall Detector or GC/MS. The Hall Detector has 1/8 sensitivity of TEA and GC/MS is approximately same as TEA. (Colorimetric methods have failed thus far to detect nitrosamines.)

Research needs for instrumentation for detection of nitrosamines are in the following areas:

- Quality validation of TEA
- Automation of TEA
- Pilot program for monitoring.

3.5.3 PNAs

The literature on PNA sampling and analysis is extensive and cannot be fully addressed in this secton. A brief review is provided in Table 3-8.

3.6 INORGANIC

The state of monitoring is adequately described elsewhere in this text. Recently, there have been new developments in monitoring which incorporate diffusional sampling.

In 1855, Fick described molecular diffusion theory in what has come to be known as Fick's Laws of Diffusion. This is physical-chemical law upon

Table 3-8.

PNAs in indoor air: Methods of collection and analysis

Personnel Monitors	Suitability	Availability	Comments
P & CAM 217 Benzene-Soluble Compounds in Air[1].	Too bulky and obtrusive for general indoor use. Yields no information on composition of benzene or cyclohexane solubles and is an order of magnitude too insensitive.	Operational	Consensus of the subgroup for organics instrumentation was that the method is currently inappropriate for monitoring indoor air. Limit of detection is 20 μg of benzene-soluble material(1). For a 1000 liter air sample (2ℓ/min. for 8 hr.), the limit of detection is 0.02 mg/m^3. This is 1/10th of the TLV for occupational exposure, and is the standard to be anticipated for exposures to the general population. Hence for quantitation (10 x the limit of detection)(2), a method with a limit of detection of 0.002 mg/m^3 is needed.

Personnel Monitors	Suitability	Availability	Comments
Silver Membrane-Chromosorb 102/high flow pumps.	For limited use because of bulk, size and cost.	Developed for occupational use by Enviro Control under contract to NIOSH.	Thoroughly evaluated procedures and quality control(3). Individual compound speciation and quantitation by GC/FID for naphthalene and quinoline and more complex PNAs, usually with 1-10 ng detection limits. The sampling train operates at air flow rates of up to 1ℓ/min. For indoor air monitoring this system is probably more suitable as an area monitor.
PNA Vapor Badge(4).	Will be small, lightweight and cheap, with quantitation for select PNA compounds adsorbed on a filter paper element.	Experimental devices requiring further development and field testing.	Detects only PNA vapors or fine liquid droplets(4). Has the advantages of being completely passive and producing specific analysis for compounds such as pyrene by direct reading of a paper adsorbent for room temperature phosphorescence(5). Still in the early stages of development - estimated 1 year for proving efficacy.

Area Monitors	Suitability	Availability	Comments
Combination pump/filter/adsorbent backup.	Enviro Control personal PNA monitoring system could be adapted for home use principally as an area monitor.	No recognized combination for general use in residences at this time.	Further development work required to minimize PNA degradation on the filter. Choice needs to be made between Tenax, XAD-2 and Chromasorb adsorbents. Protocol needed for consistent methods of use and evaluation.
Area Monitor - real-time.	------------------	Unavailable.	A need exists for a real or near-real-time instrument for monitoring and analysis of indoor sources of airborne PNAs.

Analysis Monitors	Suitability	Availability	Comments
Sensitized fluorescence for screening.	Easy, sensitive analysis for total fluorescing compounds in collected particulates - rapid, cost-effective sample throughput. "Eyeballing" the fluorescence intensity gives an order of magnitude estimate of the PNA concentration.	Recently developed by Arthur D. Little, Inc., under contract to the EPA(6). Used in the Monsanto study(7) of PNA emissions from wood-burning stoves.	Limit of sensitivity for PNAs of 10 pg in a 1 μℓ sample spotted on filter paper (equivalent to 10 ng in solvent extracted PNAs reduced in volume to 1 ml). EPA-MEG for BaP in ambient air is 20 ng/m^3 (1/10th of the standard for BaP [0.2 μg/m^3]) recommended by the Standards Advisory Committee on Coke Oven Emissions(8). To meet this demand, the method needs to be increased in sensitivity using alternative sensitizers to naphthalene and an electronic means of measuring the fluorescence intensity.
Synchronous Luminescence - screening for select PNAs.	Simple, sensitive spectroscopic analysis at room temperature for select PNA compounds at <1 ng concentrations(9).	Requires simple commercially available spectrofluorimeter to measure fluorescence and/or phosphorescence of solvent extracts.	Successful participation in NBS and EPA round-robin analysis of real-life PNA samples(10). Needs more comprehensive field evaluation.

Analysis Monitors	Suitability	Availability	Comments
EPA Level I screening.	Intended for preliminary environmental assessment within a target accurcy factor of 3 - part of a phased approach to sample collection and analysis for enhanced cost effectiveness.	Procedures are published(11) and are being followed by EPA contractors.	Solvent extracts are fractionated by LC into 7 portions. Aromatic hydrocarbons are analyzed by IR and LRMS in fractions 2,3. Sensitized and/or synchronized luminescence might be incorporated into a broadened scheme at the Level I.
Precise Analysis.	Sophisticated labortory tools (GC/MS, GC^2, HPLC, etc.) provide detailed information on the PNA composition. Equipment and analysis are suitable for analyzing a limited number of samples.	Several schemes are available but no standardized procedures are widely recognized and accepted.	In round-robin interlabortory measurements, agreement is only moderate(12). Further intercomparisons will be necessary.

References to Table 3-8

1. Benzene-soluble compounds in air, Method No. P & CAM 217, issued 01/29/76.

2. Guidelines for data aquisition and data quality evaluation in environmental chemistry, *Anal. Chem.*, *52*, 2242-2248 (1980).

3. Sampling and analytical procedures for the industrial hygiene characterization of coal gasification and liquefaction pilot plants. Report submitted to NIOSH Morgantown by Enviro Control, May 1980.

4. R. B. Gammage, A. R. Hawthorne, D. D. Schuresko and T. Vo-Dinh. "New instruments for plant area and personnel monitoring", paper to be presented at the 3rd Miami Int. Conf. on Alternative Energy Sources, 15-17 Dec. 1980.

5. T. Vo-Dinh, R. B. Gammage and P. R. Martinez, "Identification and quantification of polynuclear aromatic compounds in synthoil by room-temperature phosphorimetry", *Anal. Chim. Acta*, *118*, 313-323 (1980).

6. E. M. Smith and P. L. Levins, "Sensitized fluorescence detection of PAHs, *Polynuclear Aromatic Hydrocarbons: Chemistry and Biological Effects*, eds. A. Bjorseth and A. J. Dennis, Battelle Press, pp. 973-982 (1980).

7. D. G. DeAngelis, D. S. Rubbin and R. B. Reznik, "Preliminary characterization of emissions from wood-fired residential combustion equipment", EPA-600/7-80-040, March 1980.

8. Limit for BaP of 0.2 μg/m^3 of air recommended by the Coke Ovens Advisory Committee (29 CFR 1910 · 1029).

9. T. Vo-Dinh and J. R. Hooyman, "Selective heavy-atom perturbation for analysis of complex mixtures by room-temperature phosphorimetry", *Anal. Chem.*, *51*, 1915-1921 (1979).

10. T. Vo-Dinh and P. R. Martinez, "Direct analysis of a coal liquefaction product by synchronous luminescence techniques", *Anal. Chim. Acta*, in press.

11. IERL-RTP Procedures Manual: Level I Environmental Assessment, EPA-600/7-78-201, Oct. 1978.

12. H. S. Hertz, National Bureau of Standards, Surrogate Materials Program Meeting, January 15, 1980 at ORNL.

which passive personal dosimetry is based. With Fick's First Law as a starting point, passive personal dosimetry has grown into an area of widespread scientific research and can have significant impact on determining individual exposures to toxic chemicals.

To illustrate the short history of these devices, the earliest papers on diffusional samplers were presented by Palmes and Gunnison and by Braun at the 1972 American Industrial Hygiene Conference. The following year Reiszner and West reported on a permeation device for SO_2. Since the early 70s, the industrial hygiene community has been presented with square, round, and tubular badges, with monitors that contain liquids and others that use solid sorbents, with badges that measure a time-weighted average and monitors that yield a detailed time versus exposure profile. This list of differences is far from exhaustive.

3.6.1 Use of the Monitors

The monitors are small, lightweight, and are easily worn in the breathing zone, on the collar, lapel, on the pocket, or elsewhere. The monitors can easily be placed in rooms on walls, in aircraft, etc. The devices require that the time of monitoring be recorded. Standard practices should be followed such as recording ambient temperature, pressure and humidity, possible interferences, and some indication of the air movement.

The health specialist must realize that many of these devices are fairly new and that they have not been fully evaluated. It may be necessary for the health specialist to determine the monitoring success or failure of a given passive device for a specific application.

When the term "diffusion" is used in reference to these devices, it is meant that the device collects the contaminant after the contaminant has moved from an area of high contaminant concentration (outside the badge) to an area of lower or no concentration (inside the badge). This movement takes place through a quiescent air layer of defined geometry, called the diffusion layer. Permeation, on the other hand, finds the contaminant dissolving in a membrane, chosen for use based on its characteristics relative to the contaminant of interest. This solvation is the rate limiting step as the contaminant passes from the higher outside concentration to the sorbing medium.

3.6.2 Inorganic Monitors

Inorganic samplers, one for sulfur dioxide (SO_2) and one for mercury (Hg), were the subjects of the first AIHC presentations of diffusional monitors. The first permeation badge was also used for SO_2. Inorganic passive diffusional monitors are exclusively single compound monitoring devices, with the greatest number of devices being available for oxides or nitrogen.

Tables 3-9 through 3-12 contain tabulated information on inorganic monitors. The significant point to glean from these tables is the wide range of responses and analytical methods from which a user may choose. This can be coupled with a wide range of prices.

3.6.2.1 The Palmes Tube

The tube, when used for sampling NO_2 contains only triethanolamine-coated screen. When sampling for NO_x ($NO + NO_2$), an uncoated screen and chronic acid impregnated glass fiber disc are added. This allows for conversion of NO to NO_2. The analysis of either configuration of Palmes tube requires a reasonable amount of analytical laboratory support work (e.g., calibration curves, etc., for the spectrophotometer). The devices give a TWA value for NO_x, NO_2 and NO by subtraction.

3.6.2.2 The Pro-Tek

The Pro-Tek Colorimetric Air Monitoring System encompasses both sampling and analysis. The badge is activated upon removal from the foil pouch. After exposure, the blisters are broken allowing the reagents to mix with the absorbing solution. The badge is then placed in the reagent pack carrier and inserted in the read-out unit to determine ppm-hr exposure. This system currently has badges available for NO_2, SO_2, and NH_3. The liquids in the badge can also be removed and analyzed in a spectrophotometer and thus extend the monitor.

3.6.2.3 The Monitox System

This system includes sampling, analysis, and recordkeeping. Units are available for HCN, NO_2, phosgene, H_2S, and CO. Before use, a functional check is performed on the monitor using the matched dynamic gas generator. Once turned on, the unit relies on diffusion of contaminant molecules through a membrane to the measuring electrode in the sensor cell. The device will sound an alarm when the concentration exceeds the threshold limit value. The Chronotox is a microprocessor-based personal monitoring system, which accepts output signals from Monitox detectors. The stored data may be read out in one of two ways:

1. Digital Readout--which gives 15 minute TWAs and an 8-hour TWA
2. The Datagram which is a graphical profile of concentration vs. time, plus an 8-hour TWA.

Both data retrieval methods give hard copy documentation.

Table 3-9.

Passive Personal Monitoring Devices for: Oxides of Nitrogen

Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
MDA, Inc., also DACO Products	Palmes Tube NO_2	nanomoles of NO_2	Spectrophotometric	0-5 → 5 ppm	TEA-coated screens diffusion
E.I. Du Pont	Pro-Tek NO_2	ppm-hrs	PT-3 Spectrophotometer	10 → 100 ppm-hrs 1 - 100 ppm hrs	diffusion/absorption
MDA, Incorporated	Monitox NO_2	alarm, TWA, profile	datagram	> 0.5 ppm > 15 minutes	diffusion/electrochem
American Gas and Chemical Company	Leak-Tec NO_2	> 1 ppm color change	none required	N/A	diffusion
MDA, Inc. DACO Products	Palmes Tube NO_x		Spectrophotometric	2 - 26 ppm-hrs	diffusion/chromic acid impregnated disc/TEA adsorb
Solid State Sensors Company	Nitrous Oxide N_2O Sensor	ppm	service provided (IR)		diffusion

Table 3-10

Passive Personal Monitoring Devices for: Mercury, Hg

Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
3M	Mercury Vapor Monitoring Service #3600	T.W.A.	Service Provided (Conductivity)	0.00 → 0.20 mg/m^3	diffusion onto gold collection surface
Sipin-Environmetrics	Mercury Badge	T.W.A.	Flameless atomic absorption spectrophotometry	0.002 → 0.25 mg/m^3	diffusion through membrane onto specially treated sorbent
Solid State Sensor	Mercury Monitor	T.W.A. (μg/m^3)	Service provided (AA analysis)	N/A	diffusion adsorption onto gold film

Table 3-11.

Passive Personal Monitoring Devices for: Sulfur Dioxide, SO_2

Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
Reiszner Environmental and Analytical Labs, Inc.	MiniMonitor	ppm	West-Gaeke spectrophotometric	0.01 → ? ppm	permeation OMS membrane tetrachloromercurate (11)
E.I. Du Pont	**Pro-Tek**	**ppm-hr**	**PT-3 Colorimetric** Spectrophotometer	**10. → 100 ppm-hrs** 1- 100 ppm hrs	**diffusion/absorption**

Table 3-12

Passive Personal Monitoring Devices for: Carbon Monoxide

Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
Progressive Products Marketing Company	Dead STOP	color change	none needed	N/A	Diffusion
American Gas and and Chemical Company	Leak-Tec	color change >50 ppm	none needed	N/A	Diffusion
MDA Scientific, Inc.	Monitox	alarm, TLV exposure profile	datagram readout	> 0.1 x STD	Diffusion electrochemical

3.6.2.4 Leak-Tec

Leak-Tec Personnel Protection Indicators are plastic badges with areas specially treated to react with a given contaminant. Badges are available for ammonia, carbon monoxide, chlorine, hydrazine, hydrogen sulfide, nitrogen dioxide, and ozone. The chemical area of the badge indicates excessive exposure to a particular contaminant by undergoing a color change when a given critical accumulation is reached. This is a different mechanism from those devices requiring diffusion through a defined volume. These critical accumulations are indicated throughout Tables 3-7 through 3-12. Tables 3-13 and 3-14 show personal monitoring devices for other inorganics.

3.6.2.5 Nitrous Oxide Sensor

This is the only passive personal monitoring device available for N_2O. The N_2O sensor has two sorbent beds. The first is a dessicant section which allows the N_2O to pass to the second sorbent bed where it is collected. This badge is returned to the manufacturer for post-exposure analysis.

3.6.2.6 3M Mercury Vapor Monitoring Service #3600

This badge is one of the original passive sampling devices. The badge collects HG vapor via diffusion onto a gold collection surface. Conductometric analysis of the Gold-Hg amalgam is provided by the manufacturer.

3.6.2.7 Sipin-Environmetrics Mercury Badge

This Hg badge also collects mercury via diffusion. However, the collection takes place on a specially treated solid sorbent. TWA results are obtained via flameless atomic absorption spectrophotometry.

3.6.2.8 Solid State Sensor Mercury Monitor

It collects the mercury vapor by adsorption onto gold film. The analytical service (atomic absorption) is provided by the manufacturer.

3.6.2.9 Mini Monitor

This badge--or line of badges--is a permeation rather than diffusion controlled device. Permeation-type personal monitors are available for sulfur dioxide, chlorine, vinyl chloride, alkyl lead, methyl chloride, and Freon 12. For each of these badges, the selected toxic gas permeates a dimethyl silicone membrane and is either absorbed or adsorbed as a function of each gas' unique sorbent. The analytical determination used with each badge is a classical method--spectrophotometry or gas chromatography--frequently an adaption of a NIOSH method.

Table 3-13.

Passive Personal Monitoring Devices for Other Inorganics

Contaminant	Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
NH_3	E.I. Du Pont	Pro Tek	ppm-hrs ppm-hrs	PT-3 colorimetric Spectrophotometer	50-500 ppm 5-500 ppm	diffusion/ absorption
	American Gas and Chem. Co.	Leak-Tec	> 25 ppm color change	none required	N/A	diffusion
Cl	American Gas and Chem. Co.	Leak-Tec	> 1 ppm color change	none required	N/A	diffusion
	Reiszner Environmental and Analytical Labs, Inc.	MiniMonitor	ppm	spectrophotometric	> 0.013 ppm 0.1 → 2.0 ppm	permeation/ absorption
H_2NNH_2	American Gas and Chem. Co.	Leak-Tec	>1 ppm color change	none required	N/A	diffusion
H_2S	American Gas and Chemical Company	Leak-Tec	>5 ppm color change	none required	N/A	diffusion
	MDA Scientific, Inc.	Monitox	alarm/TWA exposure profile	datagram readout	>0.1 x STD.	diffusion/ electrochemistry

Table 3-14.

Passive Personal Monitoring Devices for Other Inorganics

Contaminant	Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
O_3	American Gas and Chem. Co.	Leak-Tec	> 1 ppm color change	none required	N/A	diffusion
Alkyl Pb	Reiszner Environmental and Analytical Labs, Inc.	MiniMonitor	μg (ppm)	spectro-photometric or AAS	>0.2 μg	permeation/ adsorption
HCN	MDA, Scientific, Inc.	Monitox	alarm/TWA exposure profile	datagram readout	>0.1 X STD	diffusion/ electro-chemistry

3.6.2.10 Dead STOP

Via diffusion of carbon monoxide, this badge undergoes a color change after a critical accumulation of CO. The detector has the ability to regenerate itself after being exposed to CO.

3.6.3 Organic Monitors

3.6.3.1 The Gasbadge, Organic Vapor Monitor, Pro-Tek and Mini Monitor

The commercial organic monitors, Table 3-15, Gasbadge, Organic Vapor Monitor, Pro-Tek and the Mini Monitor, all use an activated charcoal as the collection medium. All require gas chromatographic analysis of the collected pollutant. The Gasbadge, Organic Vapor Monitor and the Pro-Tek are diffusion devices, while the Mini Monitor is a permeation device. Each has unique properties. The Gasbadge allows for a blank field. The organic Vapor Monitor has in situ elution. The Pro-Tek has a variable sampling rate and a two-stage version. The Mini Monitor is specific for vinyl chloride.

3.6.3.2 The Gas Monitoring Dosimeter

The Gas Monitoring Dosimeter for phosgene is a color change badge which provides an alert in the 0.4 mg/m^3 range. This color change device can also be quantified by means of a color chart or analytical instrument.

3.6.4 General Monitors

3.6.4.1 Diff-Samp

The Diff-Samp, Table 3-16, is an acrylic tube with a closed liquid well at the top, filled with a solution that would normally be used in an impinger. An inert wick, kept wet by the liquid is the absorption surface. The analysis is a function of the chemistry of the absorbing solution.

3.6.4.2 Critical Orifice Personal Sampler

This device is neither diffusion nor permeation controlled. Sampling is accomplished by ambient air leaking through a critical orifice into an evacuated chamber. By this technique a portion of the whole gas is collected. The collected sample, unlike a grab sample, is time integrated. The device, Table 3-15, samples constantly for extended periods of time, from 15 minutes to 8 hours, with the maximum sampling interval dependent upon the size of the orifice and the volume of the evacuated vessel. Analysis is a function of the contaminant of interest.

All of the monitors mentioned in this report are passive, personal monitoring devices and all are commercially available. The field of passive dosimetry goes far beyond this.

Table 3-15.

Passive Personal Monitoring Devices for: Organic Solvent Vapors

Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
Abcor Development Corporation	Gasbadge	ppm-TWA	G.C.	varies	diffusion/ adsorption
3M Company	Organic Vapor Monitor	ppm-TWA	G.C.	varies	diffusion/ adsorption
E.I. du Pont	Pro-Tek 1 and 2 Stage	ppm-TWA	G.C.	varies	diffusion/ adsorption
REAL, Inc.	MiniMonitor (vinyl chloride)	ppm-TWA	G.C.	>0.1 → 2 X STD	permeation/ adsorption
MDA Scientific, Inc.	Monitox (phosgene)	alarm-TWA exposure/ profile	datagram readout	0.1 X STD	diffusion/ electrochem
SKC, Inc	Phosgene Dosimeter	0.4 mg/m^3 colorchange	color chart or analy. instrument	N/A	diffusion

(Continued)

Table 3-15. (Concluded).

Passive Personal Mentioring Devices for: Formaldehyde, CH_2O

Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
E. I. Du Pont	**Pro-Tek**	ppm-hr	Sodium Bisulfite Colorimetric Spectrophotometer	2-50 ppm-hrs	diffusion/absorptior

Table 3-16.

Passive Personal Monitoring Devices for: Other Contaminants

Manufacturer	Brand Name	Response	Analysis	Recommended Exposure Limits	Collection Mechanism
Daco Products, Inc.	Diff-Samp	TWA	varies	varies	diffusion/ absorption
MDA Scientific, Inc.	Critical Orifice Personal Sampler	TWA	varies	varies	critical leak

3.7 AIR QUALITY CONTROL

3.7.1 The Term "Control" Has Two Definitions

- A control device is the device or process that controls the variable of interest, e.g., temperature controller of a furnace. For air quality, this could be the air filter or scrubber.

- A control device can be an intelligent sensor and/or actuator system that senses the parameter of interest and contols the operation of the system or provides an alarm in cases of process failures or emergency.

3.8 RECOGNIZED AREAS OF OMISSION

- As stated earlier, participants from many colleges and universities were not present. Furthermore, Federal Agencies or professional societies which could represent the interest of the academic profession were also absent. The academic community is a vital component of this program if research is to be conducted and contemporary texts are to include the health aspects of indoor air pollution.

- Also absent from the group were persons with expertise in the sampling and quantitation of pathogens (biological hazards) and the characterization of odors.

- The working group was under-represented in the area of control instrumentation.

  There were probably other omissions, but the working group failed to identify them.

3.9 CONCLUSIONS

The programs in sampling and analytical method development, quality assurance, research and development in new instrumentations should be pursued as an interagency program in indoor air quality. A steering committee should be established to coordinate the efforts of the different agencies. This committee should also have discretionary funds to monitor the program as well as fund special R&D projects.

1.0 SUMMARY OF STATE OF THE ART OF POTENTIAL HEALTH EFFECTS OF POLLUTANTS IN INDOOR AIR

Introduction

Topics included in the state-of-the-art reports were selected because of prior visibility as potential health hazards in the indoor environment. These reports are only summaries and prepared for the purpose of identifying research needs. These summaries do not include discussions of confounding factors such as cigarette smoke which is synergistic to most substances of concern. These, of course, must be considered in any specific research plan.

It must be emphasized that various substances or factors assume various levels of importance in different clinical settings such as multistory, tightly constructed buildings, family dwellings, or mobile homes.

Nonoccupational Indoor Health Hazards from Particulates

Robert S. Bernstein, M.D., Ph.D.
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1. Nature, Sources, and Vehicles for Indoor Particulates--A considerable amount of research has been done or is in progress regarding the health effects of occupational and nonoccupational exposures to a variety of fibrous and nonfibrous dusts. For fibrous inorganic particulates, there exist some problems regarding the methods of sampling, analysis, and nomenclature which impact on the interpretation of environmental and epidemiologic studies As used herein, fibers are those particulates with an aspect ratio of 3:1 or more. Respirable fibers have a maximum diameter of 5 μm or less, but may be up to 200 μm in length. Respirable particles of irregular shape have a maximum diameter of 10 μm or less.

Respirable inorganic fibers may include the naturally-occurring asbestos fibers of all varieties (chrysotile, crocidolite, tremolite, and "amosite" which consists of a mixture of anthophylite and actinolite), some fibrous zeolites, and the comminuted talcs (with or without contamination by amphiboles or quartz). Respirable man-made fibers include mineral wools (rock wool, slag wool, and fibrous glass wool) and ceramic fibers. The latter man-made products may include binders (often a thermo-setting resin of the phenol-formaldehyde type), lubricants, and other coating materials; or they may be used as vehicles for pesticides and other consumer products. Nonoccupational exposures to these fibrous agents may occur indirectly (e.g., bystanders in shipyards), by take-home familial exposures, by environmental exposures (e.g., amphibole contamination of Lake Superior, or zeolites in the volcanic tuff near the Turkish village of Karain), or by exposure to friable consumer products during installation, maintenance, operation, or replacement.

Respirable organic fibers may include cotton, grain, tea, wood, and other vegetable dusts, as well as animal dander or feathers. With the exception of wood-dust-induced asthma, nonoccupational hazardous exposures to some of these dusts may be rare events; or their sequelae may be subtle in onset or chronic in nature and thus in need of further study. Bystander take-home exposures may result from reentrained dusts carried into the home by pets and others.

Among the sources of nonfibrous types of particulates, consumer products provide a variety of potentially hazardous respirable agents including talcs, attapulgite, or other clays (e.g., in kitty litter) and silaceous dusts from plaster, spackling compounds, and cement. Road dusts may also be a source of silaceous dust, containing small amounts of free silica. In the vicinity of heavy industrial activity (e.g., coal-fired power plants, foundries, smelters, coke plants, and incinerators), there may be periodic or continuous excessive emissions of industrial particulates, because of inadequate control technology, which infiltrate indoors. Chemicals such as oxides of sulfur and nitrogen, heavy metals, or polynuclear aromatics may be absorbed on these particulates and may affect their toxicity. The increasing cost of oil and gas for heating has caused homeowners to use wood and coal in their stoves and fireplaces, the maintenance and operation of which may result in exposures to dust like those from the industries just mentioned. The literature contains adequate documentation of the potential for "take-home" industrial exposures (e.g., lead and asbestos). Respirable organic dusts (e.g., wood dust) are the subject of ongoing research. Contact, irritant, and allergic dermatitis may occur as a result of exposure to vegetable dusts (e.g., in baking flours and biologicals). Recently residents of the States of Washington and Oregon have had to contend with uncontrollable and unpredictable emissions of volcanic ash, containing abrasive, biologically active, highly-respirable particles of plagioclase minerals and free silica. Household exposures to free silica and heavy metals may result from the use of grinding wheels, making of pottery and ceramics, etc. Another source of respirable particulates for a large segment of the general community comes from tobacco and nontobacco smoking habits.

2. Known or Suspected Health Hazards from Exposure to Particulates--Particulate agents may cause acute, subacute, and/or chronic diseases depending on the specific agent and the intensity, frequency, and duration of exposures. Most of the epidemiologic data we have, regarding hazardous exposures and adverse health effects of these particulates, have been gathered in occupational settings among relatively young, healthy, adult males, often of a particular ethnicity and sociodemographic status. Further epidemiologic data are available in the ambient air pollution literature.

The mucous membranes of the digestive and upper respiratory tracts as well as the skin and eyes are vulnerable routes of entry which are also subject to acute and subacute direct tissue injury by irritant particles (e.g., mineral wool and glass fibers, silaceous dusts, organic dusts, and absorbed chemicals). The long-term health effects of low-level, intermittent exposures to such irritants may include the onset of exacerbation of disabling chronic diseases (e.g., chronic obstructive lung diseases) in susceptible individuals. Some particulates possess pharmacologic or immunosensitizing activity which can induce asthmatic or allergic responses in susceptible individuals (e.g., vegetable dusts, pollen, and animal dander).

The chronic diseases which are suspected or known to be caused or exacerbated by these particulates in high-dose occupational settings include chronic obstructive lung diseases (e.g., byssinosis from cotton dust, chronic bronchitis from silaceous dusts, and asthma or hypersensitivity pneumonitis from organic dusts); pneumoconioses (e.g., from talc, asbestos, and silaceous dusts); and malignant respiratory diseases (e.g., pleural and peritoneal mesothelioma from asbestos, zeolite fibers, and possibly fibrous glass; bronchogenic carcinoma from asbestos fibers; and nasal cancer from wood dust.

Characterizing representative prevalent and historical exposures to these particulates in community indoor environments (homes, mobile homes, automobiles, etc.) presents very difficult problems when compared to industrial settings. Occupational threshold limit values (TLVs) have been established or proposed for most of the particulate agents mentioned above. In some instances and for only a brief time (1 day or so), these TLVs may be exceeded in the home--e.g., when laying down fiberglass or other insulation materials. However, the relevance of these standards for the general population (which includes a high proportion of hypersusceptibles such as infants, elderly, chronically ill, malnourished, or poverty-sticken) requires further evaluation. The types of medical-epidemiologic procedures necessary for case identification include:

- Standardized Questionnaire for Occupational, Environmental, and Medical History, and Respiratory or other Symptomatology
- Spirometry and other tests of lung function (lung volumes, diffusing capacity, etc.)
- PA and Lateral Chest X-Ray
- Physical Exam for Clubbing of the Fingers, Chest Auscultation, or other Target Organ Abnormalities
- Laboratory studies of immunological competence (immune proteins).

It should be noted that in the case of most malignant tumors, medical evaluation will be of no avail in prevention since there is a long latency period between exposure and ultimate response, and no reversible early indicators are known at present.

Section 2.0

ORGANIC INDOOR AIR POLLUTANTS*

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Recent interest in energy conservation has resulted in an overall effort to tighten the thermal envelopes of homes, schools, and other public and private buildings. This effort has reduced the rate of air exchange and caused concentrations of indoor air pollutants to increase to levels that can possibly harm the inhabitants. Attention has been drawn to a particular class of indoor air pollutants, the organic pollutants, primarily as a result of problems associated with consumer exposure to formaldehyde. Formaldehyde and other organic indoor air pollutants may be released from:

- Structural materials such as particleboard, plywood, paneling, and insulation
- Furnishings such as carpets, drapes, clothing, and furniture
- Combustion processes such as unvented heaters, fireplaces, furnaces, and stoves
- Consumer products such as aerosols, room deodorizers, cleaning products, and coatings
- Human activities such as cooking, smoking, and practice of arts and crafts.

The number of organic pollutants that may be present in an indoor atmosphere can be exceedingly large. As seen in Table 1, a rather substantial number of organic pollutants have been identified in home environments. Concentrations of these pollutants vary widely from home to home depending on source, strength, rate of ventilation, and other factors. In any consideration of indoor organic pollutants, it is important to remember that, although most of the chemicals are volatile, some nonvolatile organic chemicals may also be released from the use of aerosol products, smoking, and cooking.

The National Academy of Sciences (NAS) is currently preparing an extensive review of indoor air pollutants which will evaluate existing data

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* This article reflects the opinions of the authors and not necessarily their organizations, since it has not been reviewed or approved.

** Consumer Product Safety Commission.

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Table 1. Distribution of Organic Gases and Vapors Over 32 Building Materials

Compound	TVL 1976 (6)	Number of Identification	Average Concentration (mg/m^3)
Toluene	375	17	36
n-Decane	-	15	1.45
3-Xylene	435	13	30
n-Undecane	-	12	0.58
1,2,4 TMB[5]	120	12	0.29
n-Propylbenzene	(100)[1]	9	0.11
2-Xylene	435	9	5.8
Ethylbenzene	435	8	4.1
Alkane C_{10}	-	8	2.4
C3-Benzene	(100)[1]	7	0.45
n-Nonane	1050	7	0.92
α-Pinene	-	6	2.8
Mesitylene	100	6	0.04
n-Hexane	360	5	8.7
4-Xylene	435	4	7.6
$C_{10}H_{16}$	-	4	31
Δ3 Carene	-	3	0.07
C4-Benzene	-	3	0
Styrene	420	3	0.61
Alkane C7-13	(1050)[2]	3	0.36
n-Propanol	500	2	0.15
2-Butanone	590	2	0.16
1,3,5 TMB[5]	120	2	0.55
Acetone	2400	2	0.56
Disethylbenzene	-	2	0.25
Hexanol	-	2	1.45
Limonene	-	2	0.55
Butanol	150	2	29
Isooctane	(1450)[3]	2	0.11
Isopropylbenzene	(100)[1]	2	0.06
Alkane C9	(1050)[2]	2	0.97
Heptane	1600	1	7.3
Heptene-1	-	1	1.90
3-Methyl heptane	(1450)[3]	1	3.7
Freon	-	1	0.18
1,2-Dichlorethane	200	1	3.3
Pentanol	(360)[4]	1	0.25

(Continued)

[1] as Mesitylene
[2] as Nonane
[3] as Octane
[4] Danish TLV (HGV 1976)
[5] Trimethylbenzene

Table 1. Distribution of Organic Gases and Vapors Over 32 Building Materials (Concluded)

Compound	TVL 1976 (6)	Number of Identification	Average Concentration (mg/m^3)
Ethanol	1900	1	0
Meth.tert.butylester	-	1	0
Nonene-1	-	1	0
Ethylacetate	1400	1	0.11
Octane-1	-	1	0
Octane	1450	1	0.29
Decene-1	-	1	0.26
C4-Cyclohexane	1050	1	0
Methyl 2-butanone	700	1	0.4
Ketone C5	700	1	0.7
Ketone C8	-	1	0.06

and identify research needs. Since the NAS report will soon be available, the present report will confine itself to only a very preliminary discussion of the general classes of chemicals involved, their possible sources, and their general toxicology.

At present little is known about possible adverse or synergistic effects on human health resulting from long-term, low-level exposure to most chemicals. This type of exposure causes special concern in the case of carcinogens or chemicals which promote or enhance the development of cancer. Our discussion of organic indoor air pollutants will proceed according to the following outline:

A. Aldehydes

  Formaldehyde
  Acetaldehyde
  Acrolein
  Other Aldehydes

B. Solvents

  Aliphatic Hydrocarbons
  Halogenated Hydrocarbons
  Alcohols
  Aromatic Hydrocarbons
  Ketones
  Ethers
  Esters

C. Polymer Components

  Monomers
  Plasticizers
  Stabilizers
  Other Chemicals

D. Pesticides

E. Other Organic Chemicals

  Benzo-a-pyrene
  Pentachlorophenol
  Organic Acids

ALDEHYDES

The aldehydes comprise one of the most important classes of organic indoor pollutants due to their toxic effects and widespread consumer exposure. They are in general highly reactive chemicals which are strong sensory irritants, producing in some instances sensitization and, more importantly, cancer in animals.

Formaldehyde, for example, is used to make a wide array of industrial and consumer products. Major uses of formaldehyde and its intermediate chemicals, are summarized in Table 2, and include particleboard, plywood, and insulation. It is, in addition, a product of many combustion processes. Formaldehyde is a strong irritant and sensitizer that produces a variety of symptoms, depending on the mode, duration, and concentration of exposure. Generally, short-term exposure produces eye, nose, throat, and skin irritation as well as a variety of other signs and symptoms in humans and animals. Long-term exposure has been associated with changes in respiratory tract structure and function. Sensitized individuals undergo more severe, but similar, reactions at lower concentrations of formaldehyde. The National Academy of Sciences has in fact determined that there is no population threshold for the effects of formaldehyde. Of even greater concern, however, are the recent findings in a study sponsored by the Chemical Industries Institute of Toxicology, that formaldehyde is carcinogenic to rats. These findings are supported by tests showing mutagenic effects of formaldehyde in a number of test systems ranging from bacterial to mammalian.

Acetaldehyde is used in glues and deodorants, in fuels, and in the prevention of mold growth on leather. It is also present in tobacco smoke. Acetaldehyde is an irritant to skin and mucous membranes and continued exposure may cause central nervous system (CNS) depression. While no definitive association between acetaldehyde and any chronic toxic effect in humans has been established, studies in animals indicate that acetaldehyde is both carcinogenic and mutagenic.

Acrolein has been detected at a mean level of 51-102 um/cigarette in tobacco smoke. It has also been identified as a volatile component of essential oils extracted from the wood of oak trees; and it has been found in the smoke resulting from the combustion of wood, kerosene, and cotton. Acrolein is one of the strongest cytotoxic and ciliotoxic agents known and may cause impairment of mitochondrial function and DNA replication. Administration of acrolein to experimental animals also caused increased pulmonary resistance. It is mutagenic in D. melanogaster and S. typhimurium.

Other aldehydes may also be present in the indoor air. Some of these aldehydes are toxic and are known to be carcinogenic in various animal species. Thus, for example, propionaldehyde, glycidaldehyde, malondialdehyde, and 3,4,5-trimethoxycinnamaldehyde have been demonstrated to be carcinogenic.

SOLVENTS

Organic solvents and their vapors are likewise a common part of our modern indoor environment. Exposures in the home may occur from the use of aerosol products, spot removers, paint removers, cleaning products, paints, and numerous other consumer products.

Table 2. List of Products Containing Free Formaldehyde

Products	Exposure	Material/Process
Agricultural Products		Prevention of mildew on grain
Artificial Ivory	PF	Principal ingredient
Concrete	PF	Minor ingredient
Contraceptives	PF	Major ingredient
Dialysis Units	FS	Disinfectant
Dry Cleaners	FS	Waterproofing, permanent press
Dye	FS	Minor ingredient
Embalming Fluid	FS	Major ingredient
Explosive	FS	Minor ingredient
Fumigants	FS,F	Minor/major ingredient
Furniture	FS,FG	Off gasing from wood
Germicides	FS,F	Major ingredient
Hide Preservers	FS,F	Leather processing, dyeing
Hospital Products	FS,FG,F	Disinfection procedure
Inks	FS	Minor ingredient
Insulation	FG	Major ingredient
Latex	FG,FS	Major ingredient
Mining Products	PF	Floatation agent
Mirrors	FS	Minor ingredient
Mobile Homes	FG	In wood products, insulation
Paint	FG,FS	Ingredient in Latex paint
Paper	FG	Exposure to melamine resin
Photographic Supplies	FS,PF,FSB	Hardener, toner, fixing agent
Plastics	FS,PF,F	Resin production
Printing Products	FS	Ink, dyes, preserver
Rubbers	FG	Adhesive, coagulating agent
Textiles	FS,FG	Waterproofing, fireproofing, crease resistance, crush proofing, disinfectant
Shoe Products	FG	Resins, dyes, preservatives
Wood Products	FS,FG	Manufacture of plywood, particleboard and pressboard (preservative and adhesive)

Note: FG = Formaldehyde gas
FS = Formaldehyde solution
FSB = Formaldehyde sodium bisulfite
PF = Paraformaldehyde
F = Formicin

Aliphatic hydrocarbons such as propane, butane, and isobutane with less than four carbon atoms are gases. These chemicals are used primarily as propellants in many aerosol products and have no known chronic health effects. Higher molecular weight aliphatic hydrocarbons such as hexane, heptane, and octane are liquids and are used as solvents in many consumer products including aerosol products, glues, varnishes, paints, and inks. Exposure to n-hexane has been associated with demyelination and axonal degeneration of the peripheral nerves resulting in polyneuropathy in workers. Animal studies have confirmed the neurologic effect of n-hexane and its metabolites. Other aliphatic hydrocarbons induce primarily CNS depression at higher concentrations.

Halogenated hydrocarbons are excellent solvents and are widely used in many kinds of consumer products. Exposure to these solvents has typically caused myocardial depression and hepatotoxic effects at higher concentrations. A number of these chemicals also have demonstrated carcinogenic effects in animals. Chlorinated hydrocarbons include methylene chloride, a volatile solvent widely used as an aerosol solvent and flame suppressant, paint stripper, and degreasing agent. In addition to the more general effects associated with exposure to chlorinated hydrocarbons, methylene chloride is metabolized to carbon monoxide by many mammalian species. Methylchloroform is also used in large quantities in many consumer products including many aerosols and paints. This solvent also acts as a myocardial and CNS depressant. Neither of these chemicals is known to be a carcinogen. Chlorinated hydrocarbons for which there is evidence of carcinogenicity in animals include 1,1,2-trichloroethane, hexachloroethane, 1,2-dichloroethane, vinyl chloride, vinylidine chloride, trichloroethylene, and tetrachloroethylene

Alcohols are used as solvents in aerosol products, window cleaners, paints, paint thinners, cosmetics, and adhesives. They produce irritation of mucous membranes, and affect the nervous system, producing excitation, ataxia, drowsiness, and narcosis at higher concentrations. Methanol also affects the optic nerve at higher concentrations. Synergistic effects between alcohols and other solvents may be of interest.

Aromatic hydrocarbons are also extensively used as solvents. Toluene, for example, is widely used as a solvent in paints, varnishes, glues, enamels, and lacquers. It causes symptoms of fatigue, weakness, and confusion in humans exposed to 200-300 ppm for 8 hours. In contrast to benzene, there is no definitive evidence to link toluene exposure to chronic adverse hematologic effects. Chlorinated aromatics are also used to a limited extent as solvents. In addition, benzene may be present as a contaminant in many hydrocarbon products. Chronic exposure to benzene leads to the injury of the blood-forming tissues. Relationship of benzene exposure to leukemia is of major importance.

Ketones may be encountered as solvents in lacquers, varnishes, laquer and varnish removers, lubricating oils, adhesives, cosmetics, and perfumes. Some of the ketones are irritants to mucous membranes, while several cause CNS depression and pulmonary vascular dilation. Methyl butyl ketone, which is still used in a few consumer products, causes peripheral nerve degeneration, which is enhanced by the concomitant presence of methyl ethyl ketone. Commonly encountered ketones may include acetone, methyl ethyl ketone, and methyl isobutyl ketone.

Ethers used in consumer products include methyl, ethyl, and butyl ethers of ethylene glycol and dioxane. The glycol ethers are widely used as solvents, since they are soluble in both water and organic solvents, and are thus used in many oil-water combinations. They are also used as solvents for resins, paints, varnishes, lacquers, dyes, soaps, and cosmetics. Exposure to these solvents, usually in combination with other organic solvents, has caused headaches, weakness, drowsiness, disorientation, and lethargy. Dioxane produces irritation of skin and eyes, and possibly lung, liver, and kidney damage. It also causes tumors in animals.

Esters are used in plastics, resins, plasticizers, lacquer solvents, flavors, and perfumes. Some of the esters may irritate mucous membranes of the eye, nose, and throat, and some esters may cause depression of the nervous system. Commonly encountered esters include ethyl acetate, butyl acetate, and ethyl butyrate.

POLYMER COMPONENTS

Various manmade polymeric compounds are used in building structures, furniture, packing systems, clothing, and numerous other consumer products. These polymers contain unreacted monomers and other chemicals such as plasticizers, stabilizers, fillers, colorants, and antistatic agents. Recently, attention has been focused on the potential release of these chemicals into indoor air and the resultant toxicity.

Monomers, for example, vinyl chloride, esters of acrylic acid, epichlorohydrin, and toluene-diisocynate, may be released from various polymers. Esters of acrylic acid are used to prepare a large class of plastics referred to as the acrylics. The low molecular weight esters of acrylic acid are irritants to skin, eyes, and mucous membranes. Epichlorohydrin is used in the synthesis of a number of epoxy resins. Epichlorohydrin is highly irritating to all types of tissues. Inhalation of the vapors is extremely caustic to the mucous membranes in the respiratory tract. It is also carcinogenic in man, as is vinyl chloride. Toluene diisocynate (TDI) and other isocynates used in the synthesis of polyurethane are strong irritants of skin, eye, and respiratory system. They are also strong sensitizers and chronic exposure can lead to asthmatic attacks.

Plasticizers are used to provide flexibility and as a processing aid to convert a polymer into a final plastic product. Alkyl phthalates constitute the major portion of the U.S. plasticizer market. Others include expoxy esters, phosphates, adipates, polyesters, trimellitates, and dibenzoates. The toxicity data for plasticizers are incomplete. In general, they are not acutely toxic except at very high doses. Mutagenic and animal teratogenic effects have been reported for some alkyl phthalates. Recently the National Toxicology Program Carcinogenesis Bioassay Program found that di-(2-ethylhexyl) phthalate (DEHP) and di-(2-ethylhexyl) adipate are carcinogenic to both rats and mice; however, butylbenzyl phthalate was not clearly carcinogenic in rats and has no carcinogenic response in mice. DEHP accounts for more than 20 percent of all the plasticizers produced in the U.S.

Stabilizers such as organotin compounds are used as stabilizers for vinyl plastic. From an acute toxicity point of view, the compound can be considered extremely toxic. These compounds are highly irritating to tissues and cause neurologic effects.

Other chemicals in plastics: a number of chemicals used as curing agents and accelerators may also be of interest. These are diethyltetramine, mercaptobenzothiazole, tetramethylthiuram, monosulfide, and diphenyl guanidine among others. Antioxidants added to polymers such as the monobenzylether of hydroquinone and phenylbeta naphthylamine may also be possible indoor pollutants.

PESTICIDES

On the basis of EPA residential indoor monitoring data, the most frequently found pesticides and their concentrations (in ug/m^3) are: chlordane (0.1-10); ronnel (0.2-2); dursban (0.2-2); DDVP (0.5-10); malathion (0.2-2); and, diazinon (0.2-2). These pesticides are organophosphates, except for chlordane which is an organochlorine compound. The general toxic effects of organophosphates derive from their anticholinesterase activity, and include wheezing, salivation, lacrimation, sweating, nausea, vomiting, bradycardia, constriction of pupils, fatigue, tension, anxiety, restlessness, headaches, apathy, confusion, and tremors. Chlordane produces blurred vision, confusion, ataxia, cough, abdominal pain, nausea, vomiting, headaches, dizziness, and mild chronic jerking. Chlordane also causes cancer in mice.

OTHER ORGANIC CHEMICALS

Benzo-a-pyrene (BaP) is a natural product of incomplete combustion of carbonaceous material, cooking, and cigarette smoking. Its presence in cigarette smoke ranges from 0.2-12.2 ugm/100 cigarettes. It has been found to produce cancers in several species.

Pentachlorophenol is used as a preservative for wood, wood products, starches, dextrins, and glues. Its widespread use and persistent nature raise concern about human exposure. PCP has been found in human tissues, with inhabitants of log homes having higher tissue concentrations than the general population. Blood levels of 0.39 ppm in log home residents versus 0.04 ppm for the general population have been recorded. In the log homes the air levels of PCP range from less than 4 μg/m^3 to 1000 μg/m^3. PCP causes lung, liver, and kidney damage, and is currently being tested as a possible carcinogen by the National Toxicology Program.

Organic acids that may be found in indoor air include acetic acid. Inhalation of these acids causes irritation of mucous membranes, and chronic exposure may produce irritation of the respiratory system, gastrointestinal disturbances and nervous system complaints.

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INORGANIC SUBSTANCES

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Carbon Dioxide

Although carbon dioxide is produced and released into the atmosphere in much greater quantities than carbon monoxide, it is not usually classified or defined as an air pollutant. Little can be done at this time to control carbon dioxide emissions despite a regularly observed and significant (0.7-1.0 ppm/yr) annual increase in the already large concentrations of global ambient carbon dioxide (330 ppm) or the associated global climatic implications should the annual increase trend continue. The gas is a natural end product of all combustion processes involving carbonaceous material (NAS).

In a recent study Moschandreas, et al., reported that observed hourly indoor concentrations of CO_2 were constantly higher than corresponding levels in the ambient environment. The observed typical range for ambient CO_2 levels was between 100 and 500 ppm. The indoor 8-hour standard recommended by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) of 500 ppm was violated frequently. CO_2 concentrations indoors were a function of the number of inhabitants and activity patterns of the residents. In a tightly constructed building with little exchange of air flow, CO_2 could be a health problem. Since it is an end product of human metabolism, carbon dioxide rates may vary from 0.2 to as high as 5 liters per minute (0.007 to 0.18 cubic feet per minute). This gas, depending on the number of occupants and physical activity, could pose physiologic and toxicologic problems such as simple asphyxia and mild CNS depression.

Carbon Monoxide

Generated indoors by a variety of sources, including gas appliances, leaking furnaces, chimneys, vehicles in attached garages, and cigarette smoking, carbon monoxide (CO) is a colorless, odorless gas which can cause, in extreme cases, death due to asphyxiation. The aged, the very young, and those with cardiac or respiratory diseases are particularly affected by carbon monoxide.

Moschandreas, et al., reported that indoor CO concentrations were generally higher than corresponding outdoor levels in all residences monitored. Higher concentrations may be attributed to the above mentioned sources. Their study showed the effect of typical urban rush hour traffic, and typical high indoor level periods. Seasonal variations were observed, with higher CO levels during the winter months. Observed measurements of CO concentrations both indoors and outdoors are generally not considered high enough to cause a health hazard. The hourly National Ambient Air Quality Standards (NAAQS) level of 35 ppm was not violated by either outdoor or indoor levels in this study. In a tightly constructed building with low air exchange rate, CO could cause elevated carboxyhemoglobin levels in the blood, resulting in toxicological and physiological effects. The inhalation of carbon monoxide causes asphyxiation (anoxia, hypoxia) by forming chemical compounds, primarily with hemoglobin and secondly with other biochemical constituents, which in a complex manner reduce the availability of oxygen for the cellular system of the body. Symptoms such as headache, fatigue, and dizziness appear early at low concentrations. Disturbance of coordination, judgment, psychomotor tasks and visual acuity occur with HbCO saturation of 4-6 percent. The current EPA standard for carbon monoxide is 9 ppm maximum for 8-hour exposure or 36 ppm for 1-hour average exposure. These standards are designed to prevent HbCO saturation over about 2.5 percent (NAS 1977). A major hazard of carbon monoxide is the insidious nature of its toxic effects.

Nitrogen Oxides

Nitrogen oxides (NO_x) that are produced as a combustion byproduct from energy-related technologies developed by man can create local pollutant levels that are 10 to 100 times greater than natural concentrations. Nitrogen oxides are emitted from combustion sources primarily as nitric oxide (NO). Atmospheric processes may convert the nitric oxide to nitrogen oxide (NO_2) and nitric acid (HNO_3). Exposure to NO_x itself is believed to increase the risks of acute respiratory disease and the susceptibility to chronic respiratory infection. Nitrogen dioxide (NO_2) contributes to heart, lung, liver, and kidney damage. At high concentrations this pollutant can be fatal. At lower levels of 25 to 100 ppm it can cause acute bronchitis and pneumonia. Occasional exposure to low levels of NO_2 can irritate the eyes and skin.

Moschandreas, et al., showed the complexity of the dynamics involved in establishing the indoor-outdoor relationship for the interpretation of a data base generated for NO. In houses equipped with gas cooking appliances, observed indoor levels are consistently higher than observed outdoor levels. Houses with gas furnaces but electric cooking appliances display higher NO indoor levels than outdoor levels most of the time. Indoor NO concentrations in totally electric homes are almost always lower than corresponding outdoor concentrations.

Variation of the indoor concentrations of NO_x is associated with emissions from gas stoves. The observed indoor NO concentrations from totally gas houses are generally higher than the observed indoor NO concentrations in other types of houses. During the winter months the residential NO concentrations are higher than the NO levels during the summer months. NAAQS for NO do not exist; an 8-hour average residential NO standard of 2.5 ppm has been recommended by ASHRAE. The residential environment often provides a shelter from high outdoor NO_2 levels. The 1979 Harvard School of Public Health study mentioned in a General Accounting Office (GAO) report is in agreement with the Moschandreas, et al., study in that NO_2 levels were significantly higher in homes with gas stoves than homes with electric stoves. In some cases the daily peak level in gas stove households exceeded the Federal air quality standards for nitrogen dioxide.

A study done in England in 1972 compared respiratory illness of children living in homes where natural gas and electric stoves were used (Melia et al.). The study reported that children living in homes with gas stoves had more instances of respiratory disease than children living in homes with electric stoves. The researchers concluded that elevated levels of nitrogen dioxide from gas stoves might have caused the increased incidence of respiratory illness.

Sulfur Oxides

More than 25 million metric tons of sulfuric oxides (SO_x) were emitted annually in the United States. Sulfur oxides account for approximately 14 percent of the total estimated national air pollutant emissions. Released primarily in the form of sulfur dioxide, they are converted by atmospheric processes to sulfates, which interfere with normal breathing patterns, reduce visibility, and contribute to the formation of acid rain. SO_x pollutants are released by furnaces that heat homes, business and public institutions. A small amount is derived from the exhaust of cars, trucks, aircraft, and other vehicles. As a concentration of sulfur oxides in the air increases, breathing becomes more difficult, resulting in a choking effect known as pulmonary flow resistance. The degree of breathing difficulty is directly related to the amount of sulfur compounds in the air. The young, the elderly, and individuals with chronic lung or heart disease are most susceptible to the adverse effects of sulfur oxides. Sulfates and sulfur acids are more toxic than sulfur dioxide gas. They interfere with normal functioning of the mucous membrane within the respiratory passages, increasing vulnerability to infection. The toxicity of these compounds varies according to the nature of the metals and other chemicals that combine with sulfur oxide in the atmosphere.

National Ambient Air Quality Standards for sulfur oxides establish a maximum safe level of the pollutant in the atmosphere. According to these standards, atmospheric concentrations of SO_x should not exceed 0.5 parts per million (ppm) during a 3-hour period or 0.14 ppm during a 24-hour period. The annual mean concentration should not exceed 0.03 ppm.

Moschandreas, et al., observed that SO_2 concentration samples in the residential environment are very low. They attributed this to: (1) the observed ambient SO_2 levels, although higher than the corresponding indoor concentrations, are low; (2) SO_2 is relatively reactive and it is absorbed by indoor surfaces; and, (3) the high CO_2 concentrations found in the indoor environment interfere negatively with SO_2 in the monitoring instrument used.

Ozone

Moschandreas', et al., studies coincide with the National Academy of Sciences report in that indoor ozone (O_3) concentrations are lower than outdoor levels. O_3 is the surrogate pollutant for photochemical smog. Ambient O_3 levels are primarily of automotive origin, but other sources include the combustion of fuels for heat and electric power, the burning of refuse, the evaporation of petroleum products, and the handling and use of organic solvents. O_3 is highly reactive and decays rapidly by absorption on indoor surfaces. The half-life of O_3 is variable because it depends on the surface-to-volume ratio and the material of the furnishings. Owing to its high reactions, O_3 in the indoors is normally found at levels ranging from 50-70 percent of the corresponding outdoor concentrations. Moschandreas, et al., report that ambient hourly O_3 concentrations have been observed at levels higher than the NAAQS of 0.08 ppm. The NAAQS for ozone has been revised upward to 0.12 ppm since this study. O_3 is not generated indoors in great quantities. Hollowell, et al., have attributed small increases in O_3 concentrations to the use of electric stoves. The National Academy of Sciences report states that indoor exposures may be substantially reduced by appropriate choices of ventilation systems, air filters, and interior surface materials.

O_3 is a highly injurious and lethal gas at relatively low concentrations (a few ppm) and at short response periods (a few hours). The primary site of acute injury is the lung, which is characterized by pulmonary congestion, edema, and hemorrhage. Ozone in excess of a few tenths ppm may cause headache and dryness of the throat and mucous membranes of the nose and eyes

Ammonia

The main source of ammonia (NH_3) in the indoor environment would be expected from commercially available household cleaners used for washing the floors and windows and removing wax. Moschandreas, et al., introduced ammonia into the indoor environment by mopping the kitchen floor with some of the commercially available cleaning agents, 100 ml ammonia and 2 gallons of water. Measurements showed the kitchen contained the highest ammonia concentration. They observed very low levels of ammonia. The indoor standard recommended by ASHRAE is 2.5 ppm. In the office environment, workers could be exposed to NH_3 from blueprinting and copying machines. In a tightly closed house, one would experience irritation of the eyes and respiratory tract before toxic levels would be manifested.

Lead (as in Air and House Dust)

The major sources of lead in the indoor environment are from the following sources:

- Airborne lead levels. These are likely to be elevated adjacent to heavy traffic and near stationary sources, such as secondary lead refineries.

- Water supply. In some areas leaded pipes in water distribution systems may be corroded by soft, acid water creating localized zones of high exposure.

- Food. Locally grown food from urban gardens may be high in lead in some cases.

Children may ingest street dust, house dust, paint flakes, and soil through normal hand-to-mouth activity, pica, or contact with pets, toys, and other household objects. The dust is generally considered to be the largest component of background exposure to lead. The lead in indoor dust to which urban children are likely to be exposed may come from the dispositon of aerosols, from the weathering or removal of paint, or from other sources. It is not known to what extent lead enters houses through tracked in outdoor soil and street dust, by wind transport, or through building ventilation. Contributions from dust on clothing of adults with occupational exposure to high levels have been reported (Rice, et al.). Exposure of children to lead in paints remains a public health problem of serious magnitude. The greatest area of uncertainty in assessing exposures to lead-based paints is establishing how much lead from paint is actually ingested by children. Other indoor sources of lead could be hobby activities such as making pottery with lead glazes and soldering of wires for electronic devices.

Although permanent effects of lead poisoning, including blindness, mental retardation, behavior disorders, and death, can occur at excessively high exposure to lead, there is much evidence to indicate the occurrence of more subtle, reversible health effects at much lower levels of exposure (Lin-Fu); and damage to the heme-synthesis system, the renal system, and the central nervous system can occur at prolonged exposure to levels of lead typical of very urban residential environments. Preschool-age children with low levels of lead exposure from all source may be experiencing adverse health effects even though no overt symptoms are apparent.

Studies have shown that children absorb most of their lead orally, about half, in contrast to 10% in adults. In addition to lead intake from food sources, preschool children may ingest substantial quantities of lead in soil, dirt, and paint chips. EPA has set a standard of $1.5\ \mu g/m^3$ as the maximum permissible ambient air lead level under the Clean Air Act.

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Section 3.0

RADIATION

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Radiation is a normal constituent of the indoor environment. Except in unusual circumstances, the levels of radiation indoors are comparable to those in the outdoor environment. An important exception to this general rule is the radioactive gas radon and its immediate decay products where indoor levels typically exceed outdoor levels by a factor of three or more. For this reason, this summary will focus mainly on indoor radon and its potential hazards. However, a brief discussion of other sources of ionizing and nonionizing radiation affecting the indoor environment is appended for completeness.

Although radon has a number of isotopic forms, radon-222 is of most concern. It is part of the uranium decay chain and its immediate predecessor, radium-226, is ubiquitous in nature. Ordinary soils and rocks contain about 1 picocurie (pci) of radium-226 per gram, corresponding to about 1000 disintegrations per minute per pound. This decay rate is also the production rate for radon-222 atoms. Natural radium concentrations 10 times larger or smaller than this are not unusual (UN77). The inert radon-222 gas has a moderate solubility in water and a 3.8-day half-life, decaying into polonium-218 by alpha particle emission. Polonium-218 is the start of a four-member series of radon progeny, all of which have half-lives of less than 30 minutes.

Radon Progeny

Because of its relatively long half-life compared to the time air is in the lungs, radon itself is not a significant source of exposure; rather the short-lived radioisotopes which occur after radon decay contribute most of the dose, particularly the two alpha emitters, polonium-218 and polonium-214. Since the degree of equilibrium between the various short-lived radon progeny can vary appreciably with time, exposures to radon progeny are measured and expressed in a specialized unit called the working level (WL). A working level is any combination of the short half-life radon progeny in 1 liter of air which ultimately emits 1.3×10^5 million electron volts (Mev) of alpha-ray energy. This is the amount of alpha-ray energy emitted by an equilibrium mixture of 100 pci per liter each of polonium-218, lead-214, bismuth-214, and polonium-214. The working level was originally developed as a measure of exposure to workers in uranium mines and the common unit of cumulative exposure is the working level month (WLM), i.e., occupational exposure to air containing one working level of radon progency for 170 hours, a working month. Continuous residential exposure to one working level for one year would result in about 20 WLM if it is assumed that the breathing rate is less for common indoor activities than for mining and that 75 percent of the time is spent indoors (EP78).

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The mechanisms for tissue exposure from radon progeny is understood fairly well. Unlike the radon gas, the charged polonium atoms become attached to microscopic dust particles and these particulates, less than a few tenths of a micrometer in diameter, are inhaled. Such small particulates have a good chance of being retained on the moist epithelium lining of the bronchial tubes. The short-lived decay products release ionizing energy as alpha radiation before the particulates to which they are attached are cleared from the lung. However, it is not clear as to which exposed cells of the lung give rise to bronchial cancer. Therefore, most studies have correlated the lung cancer mortality with exposure conditions expressed in working levels rather than some estimate of energy deposited in tissues, i.e., the dose in rads.

Sources of Indoor Exposure

Outside air typically has an average radon progeny concentration of about one thousandth of a working level. These levels are not constant, since they depend on radon release rates from soils and the amount of dilution occurring from local weather conditions. Indoors, the situation is quite different. Because there is less rapid radon dilution due to the limited exchange rate between indoor and outdoor air (typically three quarters to one air change per hour in closed structures), radon progeny concentrations in buildings are usually several times higher than in outside air. While a comprehensive evaluation of population exposure has never been made, one set of data on the annual average radon progeny levels on the first floors of residential structures in uncontaminated areas shows a mean value of 0.004 WL (0.08 WLM per year) with some indication that 5 percent of typical residences might have a concentration greater than 0.01 WL (0.2 WLM per year). Radon progeny levels also vary with location within structures. In the study described above, the average concentration in basements was two times greater than in living areas.

It is possible that not all pathways for radon entry into structures have been properly identified, but the current belief is that the most significant pathway, in most cases, is radon migration from soil into basements through cracks and places where pipes enter. Groundwater may also be a significant radon source in some areas. Many wells have substantial quantities of radon in solution even though radium contents are relatively low. Water use in the home (showers, washing machines, etc.) results in the release of radon into the home atmosphere. The problem of elevated concentrations of radon in water is being studied extensively, but its geographical extent is not well known. A third source of indoor atmospheric contamination is building materials, from which some of the radon produced by radium decay diffuses into room air. An occasional source of high radon levels in buildings is the use of reprocessed waste materials to fabricate new building materials such as gypsum board and cinder blocks. Because reprocessing of wastes is not a well-developed industrial practice in the United States, the occurrence of such situations is probably not common. However, a few have been identified.

While there are some studies under way on the release of radon from common building materials, comprehensive data for U.S. construction materials are not yet available. Crushed rocks in solar heat storage units can be a significant source of radon. Since their use is associated with tight, energy-efficient homes, and energy efficient homes are becoming more prevalent, this potential source should be investigated on a priority basis.

Although the average level of U.S. population exposure to indoor radon decay products has not been well established, numerous studies have been conducted in specific locales where there was cause to expect elevated exposure levels. Most of these evaluations have been in areas contaminated with uranium mill tailings. Others have included areas of phosphate mining, reclaimed land in Florida (EP78), mineralized lands in Montana, energy efficient homes, and ordinary dwellings in uncontaminated areas. Table 1 summarizes most of the readily available data. Good determinations depend on long-term measurements, so that some of the data for "grab samples" given in Table 1 may not be indicative of actual exposures.

Health Effects

The emission of alpha particles by radon decay products is a significant factor in the subsequent health effects. Unlike X-rays and the electrons they produce as secondary radiation, alpha particles are heavy, doubly charged particles which produce a large number of excitations and ionizations along a very short path in tissue. For this reason, alpha particles are classified as a high-LET (linear energy transfer) radiation. Because of their dense pattern of ionization they can cause more radiation damage per unit absorbed energy than X- and gamma-radiation, and consequently the International Council on Radiological Protection has assigned a quality factor of 20 to alpha particle doses. This means that for equal doses, measured in rads, or energy absorbed, the dose equivalent, in rems, attributed to alpha particles is 20 times larger than for X-rays.

Alpha particle irradiation is demonstrably carcinogenic. Moreover, reducing the dose rate appears to have little or no effect on the amount of biological damage per unit dose that they cause. This is thought to be due to lack of effective repair processes for alpha particle damage. At low doses, the frequency of cancer from high-LET radiation increased at least proportionally with dose, but increases more slowly at high doses, because cell killing reduces the population of the cells at risk.

A significant increase in lung cancer has been observed at cumulative occupational exposures that are comparable to those which could occur from lifetime exposure to the most highly exposed members of the general public. The possibility of a threshold dose for lung cancer induction following alpha particle irradiation cannot be positively excluded. However, we are aware of no radiobiologic or epidemiologic support for a threshold for lung cancer induction due to radon progeny exposures.

Table 1. Indoor Radon and Radon Decay Product Levels[1] (RP80)

House Location	Approximate Number of Homes	Average Radon Conc (pCi/l)	Average WL	Measurement Conditions	% above .01 WL	% above .02 WL
NY/NJ - EML						
(basements)	18	2.0	.01	YR*	39%	17%
(first floors)	18	1.0	.007		17%	0%
Grand Junction, CO - CDH (background)	29	(1.1)**	.007+	YR	25%	0%
Florida						
(phosphate) - EPA&DHRS	100	(2.5)	0.015	YR	40%	25%
(background) - EPA	29	(0.5)	0.0033	YR	3%	0%
(background) - DHRS	28	(0.65)	0.004	YR	4%	0%
(background) - UF	13	0.8+	0.004+	YR	14%	14%
Butte, MT - EPA & MDHES	56	(3.3)	0.02	YR	75%	38%
Anaconda, MT - EPA & MDHES	16	(2.6)	0.013	YR	56%	25%
Alabama and Neighbor States TVA						
(phosphate slag, first floors)	5	(2.8)	0.017	Jan-May	40%	40%
(phosphate slag, basements)	17	(3.6)	0.018	Jan-May	76%	35%
(control, basements)	5	(2.8)	0.014	Jan-May	60%	40%
San Francisco Region - LBL	25	0.3	(0.002)	Grab D&W Closed++	0%	0%
Energy Efficient Homes (various locations) - LBL	17	4	(0.027)	Grab D&W Closed	76%	35%
Soda Springs, Idaho - IDHW (phosphate slag, basements)	100	1.4+	0.006+	Grab D&W Closed	25%	2%
Illinois - ANL (with unpaved crawl space)	22	6 houses > 10.0 pCi/l of Rn 9 houses > 5.0 pCi/l of Rn		Grab Sample D&W Closed		(41% > 0.03 WL)

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[1] Compiled by Office of Radiation Programs, U.S.E.P.A.

* YR means year round average under occupied conditions (air pump integrated measurements)

+ Geometric mean

** Values in parenthesis are not direct measurements, but are calculated using a characteristic radon decay products/radon equilibrium ratio of 0.5 for basements and 0.61 elsewhere.

++ Doors and windows of structure were closed for a time before taking a grab sample or continuous measurement.

Estimates of the risk due to inhaled radon progeny are based on studies of occupational exposure to underground miners. There are many uncertainties in extrapolating those results to the general population because of significant differences in such factors as age, smoking habits, and physiologic condition. Estimates of risk due to exposure to radon decay products were tabulated in a recent study of indoor radon prepared for the Radiation Policy Council (RP80) and are reproduced in Table 2.

Table 2. Estimated Life Time Risks of Fatal Lung Cancer from Radon Progeny (RP80)

Estimator	Cases per 10^6 Person WLM	Comments
UNSCEAR	200-450	30-year exposure to adults
NRC	360	all ages, 1967 U.S. population
EPA-absolute risk	350	cohort (stationary population)
EPA-relative risk	860	cohort (stationary population)
BEIR III	850	cohort (stationary population)
Victor Archer-absolute risk	1050	cohort (stationary population)
NCRP-absolute risk	130	all ages, 1975, U.S. population

All of these estimates assume that children are no more harmed by radiation than adults. While there is no evidence to support or reject this assumption for lung cancer, data on Japanese bomb survivors do not indicate a higher child sensitivity for other cancers. Even without considering this possibility, the range of risks listed in Table 2 is broad and somewhat indicative of the degree of uncertainty in current estimates of risks due to radon. Nevertheless, even the smallest of the risk estimates in Table 2 indicate that living in homes having abnormally high radon would have considerable health impact.

Nature of Exposures

Indoor exposures to radon daughters are chronic, but with widely varying levels. Indoor levels depend primarily on source strength and ventilation rates. As ventilation rates are decreased, all else being equal, levels of radon increase proportionally. The level of radon progeny increases somewhat more rapidly since the mixture of daughters approaches an equilibrium value (CL78). For this reason there has been considerable discussion of the potential effect of reducing ventilation to save energy unless remedial measures to control radon levels are introduced, or other measures simultaneously reduce the source strength.

Indoor levels are quite variable throughout the year as ventilation and source strength fluctuate. Fall and spring seasons, when windows may be open, will exhibit much lower levels of radon daughter products than in summer or winter when a home is closed up for air conditioning or heating. Other factors related to home heating and air conditioning systems can affect radon decay product exposure if they change the concentration of particulates in the air. Apparently any filtration systems, electrostatic precipitators, or even extended duct work that removes particulates can reduce exposures. Our present understanding of this is that when the concentration of air particulates becomes low enough, the radon progeny plate out on room walls and other surfaces, but further investigation is needed.

As indicated above, many of the parameters controlling indoor radon progeny levels are poorly understood and require further research. It is expected that in wet climates, moisture acts to reduce the exhalation of radon from soil and inhibit transport so that indoor levels are reduced, but soil moisture and porosity have not been measured in studies to date, nor have different kinds of housing been seriously investigated in the United States. It is expected that multistoried dwellings will have much lower radon levels, but this needs to be verified since building materials are also a factor, as had been found in Sweden. Moreover, a recent survey of residential structures in Austria indicated that the levels of radon and progeny can be poor predictors of actual exposures to inhabitants since the living pattern of the occupants plays an important, but often neglected, role. As yet we do not have good general models to predict levels in closed homes. Eventually models that can reflect how houses are actually used will be needed. In the meantime, long-term monitoring is the best source of data on human exposures.

For purposes of perspective, Table 3 indicates approximate estimates of U.S. population exposure to various sources of radiation. The exposures are given in terms of annual effective (whole-body) dose equivalent as defined by the ICRP, a quantity that can be considered as roughly proportional to overall risk. This perspective is particularly important in the assessment of possible future trends in radiation exposure resulting from the introduction of energy conservation practices that reduce air exchange rates and from a more widespread use of radium-rich waste materials in building construction. In the former case, a significant reduction in the average indoor-outdoor air exchange rate in U.S. housing will have a substantial impact on the radiation exposure of the U.S. population in the absence of appropriate control measures or "radon-reducing" conservation measures. However, it appears likely that such measures can be developed as part of an overall research and development program. This perspective highlights the importance and urgency of research into the magnitude and range of present radon exposures, the effect of various environmental parameters on such exposures (notably air exchange rates and heating and air conditioning practices) and the efficiency of possible radon control methods.

Table 3. U.S. Population Exposure Due to Various Sources of Radiation* (RP80)

Source	Annual Collective Effective Whole Body Dose - 10^6 Person rem/y
Cosmic Rays	6
Terrestrial Radiation	6
Internally Deposited Radionuclides	
Radon and Progeny (0.004 WL)	10**
All Others	8
Medical Diagnostic X-Rays	10
Fallout	1
Building Materials	1
Airline Travel	0.1

* UNSCEAR - 1980 (Draft) (NA80)

** Reduction of average air exchange rates in houses by one-half without additional controls would increase this collective dose to 20×10^6 person rem/y.

RADIOFREQUENCY RADIATION

Sources of Exposure

Virtually all of the public's exposure to radiofrequency radiation comes from radio and television broadcasting--mostly FM radio and VHF and UHF television. From field measurements at 486 sites in 15 U.S. cities, EPA estimates that only 0.6 percent of all U.S. residents are exposed to radiofrequency radiation at levels of 1 microwatt per square centimeter or more, and that half of all residents are exposed to less than 0.005 microwatts per square centimeter. There are no U.S. exposure standards applicable to the general population. The American National Standards Institute (ANSI) has suggested the standard of 10,000 microwatts per square centimeter which has been adopted in many occupational exposure situations. ANSI and the National Institute for Occupational Safety and Health are both pursuing revised occupational criteria. The EPA intends to propose standards for the general population within the next 2 years.

Radiofrequency Radiation and Health Effects

Animal studies show beyond doubt that high levels of exposure to radiofrequency radiation; i.e., far greater than 10,000 microwatts per square centimeter, convey a risk of cataracts, and produce thermal injuries. The risks from lower levels of exposure are less well established. Some experiments have shown that animals exposed to levels even somewhat below 10,000 microwatts per square centimeter can show some physical and psychological effects and may affect people, but how and to what extent are unclear. Extending the results of animal studies to human beings is difficult and uncertain.

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BIOLOGICAL SUBSTANCES

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INFECTIONS

Most infectious diseases are spread by direct transmission, or are vehicle or vector borne. For common illnesses; e.g., colds and influenza, direct transmission is the mode of spread (usually limited to a distance of 1 meter or less between people) and density of occupants in a room is thus an important factor (1). A few diseases; e.g., legionnaires disease, tuberculosis, and certain fungal diseases (e.g., histoplasmosis) can be spread by airborne transmission; i.e., dissemination of microbial aerosols to a suitable port of entry, usually the respiratory tract. Droplet nuclei (small residues which result in evaporation of fluid in droplets emitted by an infected host) and dust (under 5 μm in diameter) or fungal spores are the modes of transmission. Indoor air quality may, therefore, be a factor in the spread of the above mentioned diseases, but few studies have been undertaken on this topic (G. Mallison, CDC, personal communication).

Outbreaks of legionellosis have been linked with air ventilation systems. Legionnaires disease clinically resembles other pneumonias except that it is more likely to present with encephalopathy and diarrhea; Pontiac fever, caused by the same organism, is nonpneumonic and occurs in explosive outbreaks involving all exposed persons within a short incubation period. L. pneumophila has been isolated from cooling towers or evaporative condensers. Drifting of clouds of infected droplets given out by these devices results in the introduction of organisms into buildings, often through the air intakes of the air handling systems. Legionellosis has not so far been associated with home air conditioning units (2).

ALLERGENS

Hypersensitivity is an abnormal reaction to a foreign substance. An allergic reaction is a form of hypersensitivity that can be shown to be mediated by immune mechanisms and is clinically encountered most commonly as allergic rhinitis, asthma, or dermatitis. Common inhalant allergens are pollens, fungi, and house dust. Enclosed spaces are refuges from outdoor airborne allergens, the air concentrations being lower indoors if the windows are closed. The efficiency of air handling units to remove pollen is greatly enhanced by the use of high efficiency air filtration devices (not usually found in most offices and homes).

The numerous specific indoor occupational allergens will not be considered further: these are usually localized to a specific process or work practice. However, certain allergic syndromes have recently been identified which relate to general indoor air quality in the home and workplace, and these are described here:

1. Hypersensitivity Pneumonitis (Extrinsic Allergic Alveolitis)

Hypersensitivity pneumonitis occurs in some subjects after repeated inhalation of any of a wide variety of organic materials. Thermophilic actinomycetes have been implicated most often, but numerous fungi as well as animal proteins have been demonstrated to be etiologic agents (3). It is now widely recognized that outbreaks can occur in offices and homes (4,5) and are due to aerosols from forced air heating or cooling systems contaminated with microorganisms. The hypersensitivity reaction in these disorders usually results in chills, fever, cough, and dyspnea 4 to 6 hours after inhalation of the offending agent. In a few cases, however, there is a more insidious progression of symptoms: the patients may have pulmonary fibrosis or emphysema. The focus of contamination is usually in the recirculated water in air conditioning and ducted air heating systems or domestic cold-mist vaporizers.

2. Humidifier Fever

In Great Britain a variant of the above syndrome has been described occurring in offices, factories, and operating theaters (6,7) and has also been described in the United States (8). Biologic contamination of humidifier systems is again also considered to be the cause. Cough, dyspnea, and fever and malaise have their onset on Monday (after a weekend break) within hours of returning to work, and improving as the week progresses. As in hypersensitivity pneumonitis, the diagnosis is readily missed and the symptoms put down to "Monday morning feeling," or influenza. The reason for the difference in presentation is probably because different organisms are involved in the British outbreaks. Thermophilic actinomycetes have not been isolated: the main causal organism may be an amoeba, Naegleria gruberi. Recent CDC studies indicate that amoeba (Acanthameba) are also common contaminants of air conditioning systems (without humidification) in the United States. These organisms can cause primary amoebic meningoencephalitis, an uncommon, almost invariably fatal, disease. All reported cases so far, however, have had a recent history of swimming in lakes where the organism lives.

3. "Building Illness"

Recently, reports of illnesses of a mild allergic or irritative nature in office workers and others employed in large buildings have been received by CDC from all over the United States. Characteristically, over half of the "exposed" people are affected with nonspecific symptoms such as headache, burning eyes, and irritation of the upper and lower respiratory tracts and sinuses. Severe fatigue and diarrhea have also been reported. The symptoms come on soon after beginning work and initially clear up on leaving the building, but with repeated exposures symptoms may hang over to the following day. In view of the published reports of hypersensitivity pneumonitis and humidifier fever, CDC has investigated some of these outbreaks paying particular attention to the air handling systems; no specific cause has yet been identified. A common observation, however, is that the air handling systems are equipped with inadequate filtration and are designed for minimum air exchange with the outside in order to conserve energy (e.g., "sealed buildings"). One current hypothesis is that the concentrations of particulates of biologic origin rise to levels which can trigger off mild allergic reactions, but much more research is needed before this syndrome can be satisfactorily explained.

TOXINS

Swedish investigators have suggested that endotoxin produced by gram negative bacteria growing in water humidifier reservoirs may also cause the symptoms of humidifier fever (9). This hypothesis cannot be verified at present because of the inherent dangers in challenging volunteers to endotoxin.

To our knowledge mycotoxins have not so far been studied in buildings with fungal contamination problems. One difficulty is the absence of an adequate animal model.

CONCLUSION

1. Undoubtedly energy conservation measures resulting in low air exchange could result in a build-up of potentially harmful agents, including microorganisms and their products. Outbreaks of "building illness" already suggest that the "cost" of certain energy conservation measures is an increase in morbidity from either chemical or biologic irritants or allergens.
2. The effect of inadequate air exchange on airborne, and perhaps other, infectious diseases has not been adequately studied.
3. Increasing dependence on air conditioning units with humidification to control air quality inside buildings and factories is likely to perpetuate outbreaks of hypersensitivity pneumonitis and humidifier fever. Almost certainly, milder outbreaks of these illnesses go undetected.

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RESEARCH NEEDS

In order to assess the risk posed by pollutants that may be present in the indoor air and to make decisions as to how to make homes and public places healthier, safer, and hopefully more pleasant, it is essential to understand the health effects of pollutants contained in the indoor environment. Since risk assessments are usually made on a substance-by-substance basis, a similar approach has been used to identify research needs. It must be emphasized, however, that indoor air quality per se is the result of a very complex interaction of both chemical and physical factors. In the final analysis, in order to know the risk to the people that occupy buildings, we will have to resolve the problem of multiple risks and have some knowledge of synergism and interactions.

A few general statements should introduce more specific research needs. First, it can be said from observations of health effects induced by inhaled substances, that there is reason to believe that multiple organ systems in the body may be affected in one way or another. The respiratory system is perhaps the most vulnerable since it is the system most frequently the subject of complaint. The nervous system, particularly behavioral effects, is also a matter of concern and should be studied in more detail. There are also a number of chronic diseases for which there are no known causes and for which indoor air quality might be assessed as a contributing factor.

Secondly, the indoor environment offers opportunity to study the effects of a number of potentially toxic substances on a cross section of the population that includes the most susceptible members--the aged, the invalid, the chronically ill, the fetus, and the newborn child.

Another general comment is that nearly all efforts to study health effects are dependent on the instruments and techniques of monitoring. Two classes of instruments are needed: those that measure peak short-term exposures and long-term integrating instruments.

Research needs are provided for seven substances or classes of substances. These are formaldehyde, radon, combustion products, biologicals, organic compounds, indoor particulates, and tobacco smoke. It was difficult to establish priorities because of the differing role and level of importance a particular substance might have in individual structures or indoor environments. For each substance, attention was given to the need for epidemiology, surveillance monitoring, and toxicology.

Formaldehyde--There is a need to characterize rates of formaldehyde emissions and factors affecting these rates from various structural and consumer products in buildings. There is also need for toxicologic research concerning the neural, respiratory, and reproductive effects of formaldehyde at low levels, cocarcinogenic effects with other pollutants, mechanism of sensitization, and identification of sensitive populations.

Additional epidemiologic studies are needed concerning the relationship between health effects induced by formaldehyde and levels of indoor exposures. Current studies in mobile homes should be extended to offices and other buildings where products emitting formaldehyde are present.

Radon--The first priority for radon involves monitoring to obtain a national assessment of radon levels in dwellings. These studies might include miners exposed to lower levels present after control measures have been introduced. Nonoccupationally exposed groups may be identified for study for a more complete national assessment.

Combustion Products--There are a number of combustible fuels and combustible sources used in buildings. An emerging problem is the use of alternate fuels, such as wood, in addition to the usual fuels (gas, oil, etc.). The products of most concern are CO, NO_x, formaldehyde, and aromatic hydrocarbons. Both CO and NO_2 have a high affinity with hemoglobin and may induce chronic effects if exposure is prolonged. Combustion product studies must also take tobacco smoke products into account. Other combustion products of concern include particulates and other other organics, which may act synergistically with other indoor pollutants in producing adverse effects. Monitoring and epidemiologic studies are most critical. More is known about acute effects than chronic effects. Measurement of peak versus long-term, high-level effects are needed. Studies of chronic effects are definitely required. Several epidemiologic studies are now underway and these should be evaluated to determine what additional studies are needed.

Biologicals--High priority should be given to the study of biologic substances from two aspects, as allergens and as infective agents. Common allergens include fungal spores, pollen, mite dust, and microbial products. The indoor environment may provide ideal conditions for the growth of fungi, such as aspergillis, producing either asthma or aspergillosis. Hypersensitivity syndromes that have been identified as being associated with air handling systems are hypersensitivity pneumonitis and humidifier fever. Both are due to fungal or protozoan contamination of humidification systems. Pets, such as cats, dogs, and birds, kept in the home may also be sources of antigen-causing asthma or hypersensitivity pneumonitis. In terms of the role of indoor environment and infectious disease, it has been known for a long time that viruses and various bacteria may be transmitted in air and there is concern that sealed buildings enhance the risk to airborne infectious agents. Answers to these concerns may be learned by epidemiologic studies--such studies must, of course, be correlated with performance characteristics of the air handling system.

Organic Compounds--Apart from formaldehyde, there is also concern about possible health effects associated with other organic substances. This is in part due to the large number of organic compounds that may be present in the indoor environment. Also, it is an area where considerable basic or toxicologic study needs to be done. Organic compounds in the indoor environment may be divided into three large groups: pesticides, controlled organics (e.g., basically consumer products), and uncontrolled organics (e.g., emissions from degassing of structural materials, furniture, and furnishings). It should be recognized that there are specific organic compounds of special concern since toxicological data indicate potential health effects: aldehydes, 1,4-dichlorobenzene, nitrosamines, hydrazines, dioxins, phthalates, pentachlorophenol, and other chlorinated hyrocarbons. Others may be also included. All of these compounds require more extensive exposure monitoring before health effects can be determined. In terms of controlled organic emissions, there is need for product emission data and appropriate labeling to prevent misuse, as is required for pesticides. There should also be a central respository of toxicologic data on consumer products. It is also recognized that many of the organic chemicals that are found in the indoor air are also present in diet, water, or from industrial exposures.

It is recommended that indoor monitoring data should be correlated with HANES* data on the presence of pesticides in human blood. There also needs to be similar technology to measure other organic compounds in human blood. Exposure data may then be correlated with results of the National Health Survey data.

Particulates--Indoor particulates include fibers, dust, metals aerosols, and combustion products. Basic research is needed to characterize and measure these materials within defined environments. We must also identify pathways of particulates into the indoor environment. Particulates are vehicles for the transport of other pollutants; e.g., radon.

Tobacco Smoke--The interest in tobacco smoke is in the insult resulting from passive smoking where the mixture of smoke products is poorly defined. Priority should be given to the monitoring of smoke products, e.g., CO, formaldehyde, particulates, and NO_x. Information is needed on the decay of smoke products and their dispersion. Epidemiological studies of CO and NO_2 levels (carboxy and met-hemoglobin) should be performed. The effectiveness of air handling systems to reduce smoke products in indoor air should be evaluated. It must be emphasized that smoke products must always be studied in relation to other indoor air quality problems.

In summary, in order to study the generic problem of indoor air quality there is need to characterize features of air handling systems so they can be correlated with clinical complaints on one hand and the levels of pollutants as determined by monitoring efforts. If this is done, given the appropriate monitoring capability, there will begin to be available appropriate data to make risk assessments for effects of pollutants on people in buildings.

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* Health and Nutrition Evaluation Survey of America done by the National Center for Health Statistics.

REPORT OF THE CONTROL TECHNOLOGY SESSION
OF THE
WORKSHOP ON INDOOR AIR QUALITY RESEARCH NEEDS

December 3-5, 1980

Panelists

Dr. Janet C. Haartz, NIOSH, Chairperson
Dr. James E. Woods, Jr., Iowa State University
Dr. Amos Turk, City University of New York
Mr. William Mirick, Battelle Columbus Laboratories
Mr. Gary Roseme, Lawrence Berkeley Laboratory

March 1981

Section 1

SUMMARY OF THE SESSION

GENERAL

The Control Technology Group session of the Workshop on Indoor Air Quality Research Needs met during the afternoon of December 3 and for a full day on December 4, 1980. Panel members were:

Dr. Janet C. Haartz, (Chairperson), National Institute
  for Occupational Safety and Health
Dr. Amos Turk, City University of New York
Dr. James E. Woods, Jr., Iowa State University
Mr. Gary Roseme, Lawrence Berkeley Laboratory
Mr. William Mirick, Battelle Columbus Laboratories

Thirty-five to 40 participants were in attendance, representing trade associations, utilities, universities, Government Agencies, and consultants.

Most of the session dealt with the development of control technology research needs. Also the draft text of "A Plan for a National Program of Indoor Air Quality Research" was briefly reviewed by the group.

The following paragraphs summarize the findings and recommendations of the Control Technology group.

CONTROL TECHNOLOGY STATE OF THE ART

The Control Technology Group, other than commenting on the workshop preparatory materials for the group, did not address the state of the art for control technology. Subsequent to the workshop, the Control Technology Panel members prepared descriptive materials for each of the technologies: ventilation, source removal/exclusion, contaminant removal, and product substitution.

Ventilation has been used for centuries for comfort conditioning. During the past century standards have been developed and used for ventilating public access buildings. Generally these types of building standards are prescriptive, requiring minimum air flow within the indoor air space. On the other hand, occupational standards are performance-oriented, being directed at concentrations of pollutants in the indoor air space.

Ventilation may be natural or mechanically forced, or infiltration simply (unintentional air leakage into and out of indoor spaces). Forced systems may be thermostatically or manually controlled and may include air cleaning systems for make-up and/or recirculated air.

An innovative approach in building ventilation is the use of air-to-air heat exchange ventilators, which reduce the energy costs of heating as cooling outdoor ventilation air. These devices are designed to save energy by (in winter) transferring heat from the exhausted air to the intake air. During summer air conditioning periods the reverse transfer would operate.

Contaminant removal from indoor air has been successfully used for many years in the form of particulate filters (including electronic air cleaners). Gas removal devices, such as activated carbon or activated alumina, are also common.

When air cleaners are installed in an HVAC system, the entire air space is cleaned after being "contaminated." When the cleaner is interposed between the source and the indoor air spece, such as in a range hood, contamination of the occupied space may be avoided.

Problems with contaminant removal systems include capture in efficiency, noise, pressure drops, high cost, and in rare cases, the possibility of producing contaminants themselves. One system that can circumvent some of these problems uses carbon adsorption, which has been used in range hoods. Present systems do not include an effective means of indicating saturation and need for maintenance, however.

Source removal and exclusion may be the most effective means of contaminant control, the former being a permanent solution to a contamination problem. Exclusion means installing a barrier or a sealant and is not considered permanent, since both are subject to rupture and subsequent leakage. The problem of asbestos in buildings is serious and corrective measures include source removal and exclusion. Sealants are being developed and tested, but are not permanent solution and their correct application is difficult. Removal systems are being researched; the development of safe removal techniques is hampered by the very small size of asbestos particles.

Radon entry from soils through foundations is locally significant. Various sealing, ventilation, and filtration techniques are being tried in high radon areas. Exclusion may be accomplished by subfloor ventilation, by sealing cracks and holes, or by applying impermeable membranes on porous surfaces. Correction of the problem is expensive and more of the techniques have been adequately tested in the U.S. cost problems appear to be frequently more severe in retrofit situations.

Tobacco smoke is considered to be one of the most offensive contaminants in public (i.e., nonresidential) spaces. Control of tobacco smoke can be achieved by source removal, by particulate and gaseous removal devices, or by dilution.

Biologic contaminants must also be controlled, whether they are introduced to the occupied space through ventilation with outdoor air or are generated indoors by the occupants or by processes. Airborne contaminants can be controlled by removal with filtration devices, by irradiation by ultraviolet lamps, or by dilution with outdoor air. Surface contaminants can be controlled by sealing, containing, or cleaning the contaminated surfaces.

Product substitution is a relatively new technique as applied to control of indoor air quality. It is generally spurred by user complaints. An example of substitution is solid deodorants to replace sprays. A problem with substitution is the possibility of replacement with a similar or greater hazard.

AREAS OF OMISSION

The Control Technology Panel did not, for lack of time, seriously consider product substitution as a control technology. Also the emphasis was on residential indoor air with a tendency to neglect nonresidential indoor environments. Finally, the Panel did not systematically review the research inventory as a prerequisite to research needs development.

RESEARCH NEEDS

The Control Technology Group identified many research needs in the control technology area. These needs followed a list of general research to acquire information on problem definition requisite to control technology development. Those problem definition needs include pollutant identification, source identification, determination of emission rates and mechanisms, description of transport mechanisms, determination of health risks, and development of evaluation methods.

Several needs were listed for ventilation research that dealt with rate measurement techniques, effects of ventilation operational configurations, acceptability and efficiency of devices (including air-to-air heat exchangers and general space versus spot ventilation), and effectiveness of various systems in reducing pollution while conserving energy.

Contaminant removal research needs included several on adsorption filters, such as their efficiency versus time, how to signal adsorbent saturation, and potential emissions from saturated absorbent. Other research needs dealt with evaluating the effectiveness of other filtration systems and various kinds of applications. Various filter media should be evaluated, end-of-service indicators would be developed, and electrostatic particulate removal should be examined. Suggestions were made to evaluate other techniques such as climate control for control of pollutants, the use of indoor plants, and other natural sinks.

Source removal and exclusion research needs emphasized determination of emission rates from various sources. Control technology research needs included the development of building technologies to exclude sources, examination of human activities that could exclude sources, in addition to examining protective barrier coatings and physical removal techniques.

Product substitution was not examined in detail by the Control Technology Group although suggestions regarding potential identification, product labeling, ingredient labeling, and the need for cost/benefit criteria were presented. One important point brought up here was the fact that substitution in building materials can require massive economic changes because of the large quantities of materials used.

Secton 2

REVIEW OF THE STATE OF THE ART FOR INDOOR AIR QUALITY CONTROL METHODS

GENERAL BACKGROUND

In focusing attention and resources on outdoor pollutant sources and contaminant concentrations, the scientific and regulatory communities may have neglected an equal or perhaps a more important component of total exposure to air pollutants: The component is that which occurs in the indoor environment. Individuals may spend as much as 90 percent of their time indoors. Most of the pollutants to which people are exposed are found indoors, as well as outdoors. The predominant component of exposure to some of these pollutants occurs indoors.

Of increasing concern are the effects that energy conservation measures may have on the air quality of indoor environments. One of the most popular and cost-effective means of conserving energy is weatherization--the reduction of outdoor air infiltration--which can result in a buildup of indoor-generated pollutants. In larger buildings ventilation rates are reduced to save energy with a similar indoor air quality effects. Thus, elevated indoor air pollutant concentrations, which in some instances are already a problem, may be further accentuated by the implementation of certain energy conservation measures. Unless specific controls are simultaneously applied, or intervening factors occur, either the pace of building energy conservation programs will be constrained or indoor air quality will suffer.

There are three general objectives relating to the indoor environment that are functionally related so that, in the absence of other measures, only any two of the three can be realized simultaneously. The purpose of measures to control indoor contamination is to break the web of dependence so that all three objectives can be attained at the same time. The three objectives are:

1. Maintain thermal comfort (not too cold in winter or too hot in summer)
2. Maintain good indoor air quality (not toxic or odorous)
3. Keep energy costs low.

Traditionally, the variable subject to control is air exchange rate which is made up from ventilation and infiltration. If this variable is extravagant, objective (2) and a choice of either (1) (at high cost) or (3) (at the expense of thermal comfort) are achieved. If the air exchange rate is too restricted, objectives (1) and (3) are achieved, but good indoor air quality (2) must be sacrificed. Indoor air quality controls should be designed to reduce the dependence of objectives (1) and (2) on air exchange rate, either by improving its efficiency, by substituting air cleaning methods for it, or by removing, excluding, or providing a substitute for the source.

In the following pages, a summary of indoor air quality control technology concerns is presented. A more comprehensive treatment of this area is being developed by a "Committee on Indoor Pollutants" of the National Academy of Science (see Reference 26). That report, which should be published in 1981, includes a more extensive consideration of control aspects (sources of emissions, exposure rates, control methods, equipment and strategies) than it is possible to include in this workshop report.

Types of Indoor Environment, Sources, and Pollutants

Despite the increasing concern about indoor air quality, a concensus has not yet been reached regarding the definition of various types of indoor environments. An indoor environment is any enclosed environment which is distinguished from the open, outdoor environment. The separation between occupational and nonoccupational indoor environments is not clear, because an indoor environment may be a workplace for one individual but not for another. In this section, indoor environments will be defined according to their function. The following indoor environment types may be identified:

Domicile:	A place of residence, such as single family dwellings, multifamily dwellings, public housing, row houses, apartments, or condominiums
Educational:	A building used for classrooms or instructional functions
Laboratory:	A building used predominantly for research and diagnostic work and not necessarily for instructional use
Medical:	Buildings used for health care facilities, such as hospitals, clinics, medical centers, sanitariums, day nurseries, infirmaries, orphanages, nursing homes, or mental health institutions
Office:	Buildings such as offices, civil administration buildings, or radio and television stations
Public Assembly:	Buildings where groups of people gather for different functions, such as theaters, restaurants, cafeterias, retail stores, art galleries, museums, banks, post offices, court houses, assembly halls, churches, dance halls, field houses, coliseums, passenger terminals, or libraries

Rehabilitation:	Nonhealth care buildings used for instructional purposes but not of the regimental classroom type; pertaining more toward readjustment, such as jails, prisons, reformatories, or halfway houses
Warehouse:	Buildings used for storage of materials and supplies, such as storage facilities, maintenance facilities, garages, airplane hangers, or bus barns
Industrial:	Buildings such as factories, assembly plants, foundries, mills, power generating plants, telephone exchange facilities, water and wastewater treatment facilities, solid refuse plants, zoos, greenhouses, aviaries, arboretums, or other facilities requiring environmental control for process control

A broad classification of pollutants, presented below, relates pollutants to their source, and therefore to potential control technology.

1. Pollutants infiltrated from outdoors. All pollutants found in the outdoor environment (e.g., NO_x, SO_x, CO, TSP, microbial spores, dust, pollen, etc.) can infiltrate indoors. In addition to outdoor air, soil gases (e.g., radon) may directly find their way into buildings in significant quantities.

2. Pollutants generated by indoor activities. Domestic sources include routine cooking, cleaning, smoking, hobbies, use of sprays, and emissions from the human body. In the industrial workplace, other sources are likely to be often overshadowed by industrial process emissions.

3. Pollutants transported indoors. Pollutants found in an environment may be transported from a second environment as an individual moves from one space to another. Pollutants found in indoor industrial environments may be brought into residential environments. Soil, along with all chemical contaminants often associated with soil, may be transported indoors from outdoor environments. Bacteria are often carried by individuals from one environment to another. Pesticides may be carried from outdoors to indoors (for example by termites).

4. Pollutants emitted from building construction materials. Building materials, including concrete, wood products, paint, plastics, and insulation material may emit pollutants such as radon and its progeny, asbestos, formaldehyde, and others.

Control Methods

Four types of control technologies are available to control the quality of indoor air: (1) ventilation, (2) source removal/exclusion, (3) contaminant removal, and (4) product substitution. The status and general applicability of these techniques are summarized in Table 2. A fifth method, education of the inhabitants, does not involve a systems control approach, yet it may well be an effective approach in controlling indoor air quality. Any indoor air quality control strategy should satisfy health, safety, comfort and energy conservation objectives while minimizing costs and changes in the way of life. The four control methods are not always independent. A simple steady-state mass balance for a system which does not recirculate air indicates that a relationship among those methods can be expressed as:

Table 2. Indoor Air Quality Control Technologies

Control Method	Comment
Forced Ventilation	Widely used in industrial, institutional, commercial, residential, and transportation environments. May require substantial energy for heating and cooling, or may improve energy efficiency, depending upon control system.
Natural Ventilation	Efficiency as a control strategy is not well documented, but is expected to vary considerably. Noise considerations and high indoor pollution levels may limit effectiveness.
Infiltration	Ordinarily unintentional air leaks; energy waste is closely associated.
Local Ventilation and Heat Exchangers	Efficient control strategies for both small and large buildings; research needed to quantify the efficiency of each strategy.
Source Exclusion (entry prevention) Source Removal	Can be very effective but requires extreme care in application to assure effectiveness; retrofit application may be very costly.
Continuous Contaminant Removal	Pollutant dependent; effectiveness requires further documentation. Contaminant control devices are often large, expensive, noisy and require maintenance. May be more appropriate for large building complexes than for residences.
Source Substitution	Has not been widely implemented; is effective if the source is substituted with an equally functional alternative that does nto generate any indoor pollutants.

$$C_s = C_o + \frac{\dot{N} - \dot{E}}{\dot{V}} \tag{1}$$

where: C_s = indoor concentration

C_o = outdoor concentration

$\dot{N}$ = net generation rate of contaminant indoor (affected by source removal, exclusion, and product substitution)

$\dot{E}$ = contaminant removal rate

$\dot{V}$ = air exchange rate (ventilation air and infiltration).

Source removal and exclusion and product substitution involve methods which minimize the net generation rates of contaminants indoors, $\dot{N}$. These methods currently include:

- Isolation of the source from the indoor environment, such as product substitution or prohibition of smoking in certain areas (27, 28)
- Containment of the source by treatment with paints or other barriers
- Local exhaust such as biological cabinets in laboratories (13), or kitchen range hoods (9).

Source control is probably the most cost-effective and energy-efficient method of indoor air quality control, but also provides the least assurance of control to the occupants, if other methods are not present. For example, if removal control, $\dot{E}$, has not been installed, and ventilation, $\dot{V}$, has been minimized for energy efficiency, only a small perturbation in $\dot{N}$ can be tolerated without excessive changes in the indoor concentration, C_s, at a constant value of outdoor concentration, C_o.

Ventilation or dilution control, which pertains to methods that affect $\dot{V}$, is the most common method of indoor air quality control in non-industrial facilities. This method of control may be achieved by:

- Infiltration through cracks around windows, doors and construction joints (30)
- Natural ventilation through open windows and doors, and through other openings or vents designed for that purpose (31, 32)
- Forced or mechanical ventilation systems which include supply or exhaust fans, and which also may include dampers and filters (21).

Dilution control methods may be applied independently or in combination. Their relationships are shown schematically in Figure 1. Note that when dilution control is employed, the presence of a contamination source, with generation rate $\dot{N}$, is implied.

Removal control, which pertains to methods that affect $\dot{E}$, is commonly used as an alternative to, or in combination with, dilution control to reduce indoor concentrations by means of air cleaning devices. These can be located either in the forced air systems, as shown in Figure 1, or directly in the occupied space. Examples of this latter type of control are fan-filter modules which are often used in hospitals (35), laminar flow clean benches located in electronic and biomedical laboratories (36), or simple particle filters on residential furnaces.

STATE OF THE ART IN VENTILATION

Historical Perspective

Ventilation of indoor spaces has been recognized as necessary for several hundred years, but research on required ventilation rates dates back only to the nineteenth century. In 1824, Tredgold proposed that four cubic feet per minute (cfm) per person of outdoor air was necessary for removal of CO_2 in enclosed spaces (1). By 1893, the accepted minimum ventilation rate was 30 cfm per person, based on Billings' recommendations for control of other unknown contaminants (2). In 1895, the American Society of Heating and Ventilating Engineers (ASHVE) agreed to develop a ventilation standard at its First Annual Meeting (3). A minimum of 30 cfm per person ventilation air was adopted in that standard, and by 1925, the codes of 22 states in the United States had promulgated that value (4).

The research of Yaglou, et al., in the 1930's showed that the amount of ventilation air required for "odor-free" environments was a function of available air space per person (5). Based on these studies, the American Standard Association (ASA) adopted a minimum ventilation rate of 10 cfm per person in 1946 (6). In 1973, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) revised the ASA odor-based standard and reduced required ventilation rate to 5 cfm per person for energy conservation; also specified were recommended values for comfort or odor-free environments which were two or three times greater than the minimum values (7). This standard was adopted by the American National Standards Institute (ANSI, formerly ASA) in 1977 and designated ANSI Standard B 194.1.

ASHRAE also developed another standard for energy conservation in 1975 (8) which conflicted with the ASHRAE Standrd 62-73 (ANSI B 194.1). That standard stated that the minimum values shall be used for design purposes, thus effectively deleting the recommended values. To resolve this conflict and to incorporate new information available on ventilation control, ASHRAE has recently revised Standard 62-73 (9). The revised standard (designated ANSI/ASHRAE 62-1981) specifies required ventilation rates for smoking and nonsmoking spaces. Generally, the nonsmoking values are similar to the previous minimum values, and the smoking values are similar or greater than the previous recommended values. In addition to these changes (now called the "Ventilation Rate Procedure"), ANSI/ASHRAE 62-1981 also describe a new "Indoor Air Quality Procedure." This latter procedure allows new, creative methods of control if assurance is provided that concentrations of indoor contaminants will not be excessive. Guidelines for concentrations are given, but control methods are not.

[Editor's Note

The ASHRAE standards are widely used by building code officials and designers attempting to ensure reasonable air quality inside buildings. Such standards are badly needed. As can be seen from the historical development of ventilation standards, has a single criterion such as order or carbon dioxide levels have served as the basis of the minimum ventilation requirements. The new ASHRAE standard, while now addressing more pollutants, is widely acknowledged as reliant on an insufficient data base of pollutant levels in buildings, the health effects caused by exposures to those pollutants and nonventilation control methods. For example, research since the ASHRAE standards' promulgation has shown that much higher levels of ventilation are needed to dilute tobacco smoke odor. On the other hand, recent radon guidelines and standards in other countries are higher than the ASHRAE radon guideline. Thus, the ASHRAE standard is not viewed as definitive, but as based upon the optimum of a group of experts at a particular point in time. These standards are likely to change in the future as more research is performed; ASHRAE recognizes this likelihood, and updates its standards, normally, on a 5 year basis.]

Criteria

Systems for environmental control can be designed to meet either *performance* or *prescriptive* criteria. To a limited degree, performance criteria are now specified for industrial environments. Specifications for maximum allowable concentrations (MAC) and time-weighted averages (TWA) have been developed to protect the workers from potential industrial health hazards (11). Generally, the methods to achieve these criteria are not specified, and the responsibility to *provide* and *maintain* acceptable conditions resides with the designer, owner and operator of these systems. Although ANSI/ASHRAE 62-1981 now includes a performance type "Indoor Air Quality Procedure," environmental criteria are usually prescriptive for nonindustrial (i.e., residential and commercial) facilities. Either volumetric air flow rates are specified per person or per unit area, or room air exchange rates are specified. Unlike performance standards, compliance with prescriptive standards is generally assumed to be met if systems are designed and installed according to the appropriate standards. The standards do not address the need for periodic evaluation of the performance of these systems during their subsequent years of operation.

Prescriptive values are usually established to meet both objective and subjective criteria. Four objective criteria are generally recognized as the basis for ventilation control:

- Provision of sufficient O_2 for normal respiration
- Dilution of contaminants within the occupied space
- Pressurization of occupied spaces to control infiltration or exfiltration
- Dissipation of thermal loads present in occupied spaces.

The criteria do not emphasize control strategies other than dilution.

When ventilation is provided for dilution, pressurization, or heat dissipation, sufficient outdoor air is supplied so that maintenance of O_2 concentrations is seldom a problem. Outdoor air, however, may introduce pollutants to the indoors. Dilution, pressurization and thermal dissipation, however, are less dependent on one another.

Ventilation rates or air exchange rates for dilution control are specified in standards such as ASHRAE standards (7, 9), and the HUD Minimum Property Standards (12). Pressurization values are usually only specified for critical areas, such as laboratories (13, 14) and hospitals (15). Ventilation rates for dissipation of thermal loads are usually not specified, but this method of control may be used as described in the ASHRAE thermal comfort standard (16).

In addition to objective criteria for indoor air quality (i.e., mass or thermal concentrations), subjective responses of the occupants to the environmental conditions must be considered. Subjective criteria for indoor air quality are usually expressed in terms of (17):

- Perceived odor intensity
- Odor acceptability.

Perceived odor intensities are expressed in terms of odor threshold (i.e., the concentrations of the odorant necessary to produce a "just detectable" odor) and in terms of perceived odor magnitudes for suprathreshold intensities (18). The levels of suprathreshold intensities, or perceived odor magnitudes, depend on the degree of pleasantness or unpleasantness associated with the odor. Moreover, combinations of odors are not additive, and behavioral responses to combined odors are not well known (19).

Because dilution is commonly used for odor control, ventilation rates in standards, such as those previously mentioned, are often specified with consideration given to the function of the space. For example, ventilation rates in conference rooms where smoking is permitted may be specified as two or three times those for theaters, where smoking is not permitted, even though the occupancy densities may be identical.

Economic evaluations are currently based on low first-costs of nonindustrial systems. However, after construction is completed, owners and operators often try to minimize operating costs. A common result of minimized first cost design, and subsequent improper operating procedures, is that neither cost reduction nor acceptable indoor air quality may be realized (20, 21).

Energy criteria often translate to economic criteria, but some noneconomic factors (e.g., socio-political) must also be considered. Whether resulting from social concerns or economic values, efforts are currently underway to reduce energy consumption in buildings. On a national basis, ventilation has been reported to account for 25-50 percent of the annual energy consumption in buildings (21, 22). Accordingly, significant governmental funding has been directed to research projects and energy auditing procedures which may result in reduced ventilation (24, 25). Concern regarding these reduced rates has also resulted in a Government-funded study on indoor pollutants by the National Academy of Sciences (26) and other studies. It is expected that the NAS Report will be published early in 1981.

Ventilation System Description

For the simple case of no air recirculation for the occupied space (i.e., 100% ventilation or outdoor air) and no contaminant removal control (i.e., $\dot{E} = 0$), Equation (1) indicates that the contaminant concentration indoors, C_S, varies inversely with the air flow rate $\dot{V}$,* when referring to indoor generated pollutants. This presence that the outdoor concentration of the contaminant being studied is negligible and assumed to be zero. This relationship is the basis for the ventilation rates commonly specified in current standards (7, 9, 12).

When circulation air is used in a system, which is common practice for residential and commercial systems, the air entering the occupied space is no longer considered ventilation air, but supply air, as shown in Figure 1. Thus, supply air is a thermally conditioned mixture of recirculated and outdoor air.

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* Editor's Note: This sentence suggests that as ventilation rates approach infinity, indoor contaminant concentrations approach zero. This is correct for only indoor-generated pollutants, for pollutants introduced in ventilation air (outdoor air) indoor concentrations will approximate outdoor levels.

Typical residential forced air systems have been designed to recirculate 100% of the supply air and infiltration has been depended upon for dilution control. In this case, a filter, if present, is located in the recirculation air stream. The steady-state indoor concentration can be expressed by Equation (1) if the air flow rate, $\dot{V}$, is taken as the infiltration rate, V_i, only. As energy conservation efforts have been adopted, the amount of infiltration air rates have often been reduced to less than 0.5 air changes per hour in new construction (12, 30). Reductions in air infiltration rates in existing residences have not been reduced to levels as low as those in new construction; reductions in infiltration are still substantial. In new residences, indoor air quality may be significantly degraded if care is not taken to provide alternative control strategies (26, 33). Conversely, with the alternative strategies, drafts and cold wall effects caused by infiltration can be reduced resulting in improved thermal comfort as well as energy savings (16).

Forced air systems for commercial facilities vary considerably; some may employ 100% recirculated air, some may be required to use 100% outdoor air (14, 15), and some may use thermostatically controlled mixed-air systems (7, 9, 15). As shown in Figure 1, the location of air cleaners in these commercial systems may also vary. For these systems, the steady-state indoor concentration can also be expressed by Equation (1) with air flow rate, $\dot{V}$, assumed to be the sum of the variable infiltration and outdoor air rates ($\dot{V}_i + \dot{V}_o$). As in residential facilities, energy conservation efforts in commercial buildings have resulted in reduced infiltration rates. In addition, the ventilation systems are often deactivated during reduced occupancy periods. If the major sources of contamination within a facility are the occupants, the deactivation may not cause degradation of the indoor air quality for the remaining occupants. Conversely, if the sources of contamination are processes or materials which are independent of the occupancy density, deleterious effects to the remaining occupants could result.

Thermostatically controlled mixed-air systems are of particular concern today because of their energy implications. Advice and demands have recently caused set-points of the mixed-air controllers to be reset to higher values, deactivation of the thermostatic function of these systems, manual adjustment to a minimum amount of ventilation, or complete deactivation of the systems (24, 25, 34). Unfortunately, these courses of action have usually been counterproductive. Thermostatically controlled mixed-air systems, with either temperature or enthalpy control (i.e., "economizer" systems), were probably designed to provide supply air conditions to meet cooling requirements imposed by thermal loads (21). Thus, the desired amount of outdoor air introduced for cooling may exceed the minimum required for mass air quality control. Moreover, the proper use of mixed-air control allows refrigeration equipment to remain deactivated when thermal conditions of the outdoor air are sufficient to meet the cooling loads. Conversely, if these mixed-air control systems are improperly operated (i.e., set to higher set-points), thermal comfort may be degraded or additional refrigeration loads may be required which would increase energy consumption.

STATE OF THE ART IN CONTAMINANT REMOVAL

Historical Perspective

Contaminant removal using pollution control devices (generally some type of filter) has been successfully used in industrial, commercial, institutional, and residential indoor environments in lieu of or in addition to ventilation (dilution). Such devices are most often used in air recirculation systems or mixed air systems where energy conservation is economically important, where stabilized and/or "pure" air quality is desired, or where make-up air is nonexistent or in limited supply (e.g., space and submarines).

Examples of common applications of contaminant removal devices are:

- Furnace/air conditioner (low efficiency) particulate air (disposable) filters
- Medium to high efficiency particulate air filters
- Electronic air cleaners
- Activated carbon and activated alumina gas cleaners
- Ultraviolet lamps (incineration).

Contaminant removal is a much newer technology than ventilation. The common applications have evolved, for the most part, in the last two generations, along with automated space heating and cooling systems, sealed buildings, and the associated use of fuels such as gas and electricity.

Contaminant Removal Systems Description

Air cleaning devices for residential or commercial systems may be classified as:

- Particle removal devices which include mechanical filters and electronic air cleaners (37)
- Gas and vapor removal devices witn contain sorbents, such as activated charcoal or activated alumina (38).

The removal rate of the indoor contaminant $\dot{E}$, in Equation (1), can be expressed as:

$$\dot{E} = \varepsilon \dot{V}_u C_u \qquad (1)$$

where: ξ = efficiency of contaminant removal device

$\dot{V}_u$ = air flow rate through contaminant removal device

C_u = concentration of contaminant in the airstream entering the contaminant removal device.

The upstream air flow rate, $\dot{V}_u$, is usually known explicitly: for fan-filter modules, $\dot{V}_u$ is given as part of the rating of the device. In central systems with 100% recirculated air or 100% outdoor air, $\dot{V}_u$ is the same as the air flow rate through the system fan. In mixed-air systems, $\dot{V}_u$ is the sum of the outdoor and recirculated air flow rates. It should be noted that V_u in larger systems may vary depending on changes in system resistances or variable volumetric flow rates (39).

The contaminant concentration in the air entering the contaminant removal device, C_u, should be equal to the concentration in the occupied space for fan-filter modules and 100% recirculated air central systems. If stagnation or stratification exists within the occupied space, the concentrations to which the occupants may be exposed could be significantly different from those entering the air cleaning equipment (22, 40). For 100% outdoor air systems, C_u should be the same as the ambient air. But, if the outdoor air intake is not carefully located, these concentrations can be influenced by local effects, such as automobile emissions (41), particle entrainment (42), or "short circuiting" from system exhaust ducts (43). The concentrations, C_u, in mixed-air control systems can vary between those in the occupied space and those in the outdoor air, depending upon the mode of mixed air control.

The efficiency of the contaminant removal device, ξ, must be expressed as a dimensionless fraction. It is usually determined as the complement of the penetration, P, of the contaminant through the device:

$$\xi = 1 - P \qquad (2)$$

where $P = \frac{C_d}{C_u}$

C_d = concentration of the contaminant in the airstream leaving the contaminant removal device.

As seen from Equation (1), an increase in the removal rate, $\dot{E}$, has the same effect as reducing the generation rate, $\dot{N}$ (i.e., $\dot{N} - \dot{E} \rightarrow o$). The result, therefore, is to decrease the difference between the indoor and outdoor concentrations. In fact, with sufficiently high values of air cleaner efficiency, and of air flow rate through the air cleaners, V_u, the removal rate, $\dot{E}$, will exceed the generation rate, $\dot{N}$, and the indoor concentration, C_s, can be less than the outdoor concentration, C_o, independent of the value of the air flow rate, $\dot{V}$ (21, 36).

A distinction must be made between two modes of applying contaminant removal devices (air cleaners) to the purification of indoor air. In one mode, the air cleaner is interposed between the source and the indoor environment. Such a system serves in effect as an attempt at source exclusion.

In the second mode, the air cleaner treats the indoor air after the contamination has been more or less thoroughly dispersed therein. Typical examples of such devices are air cleaners applied to central HVAC systems or free-standing air cleaners located somewhere in the building. In the ideally simple case in which both the contaminant sources and the treated air are completely and instantaneously mixed in the entire indoor space, the concentration of contaminants drifts exponentially to a steady-state value that depends on the volume of the space being treated, the rate at which contaminants are being generated, and on the air handling capacity and contaminant-removal efficiency of the air cleaner (44, 45, 46).

The situation in real HVAC systems is complicated by various other factors, such as inhomogeneous dispersal of contaminants, variations in rates of generation, and progressive changes in the efficiency of the air cleaner. Approaches to some of these complexities have been studied by various investigators (21, 22, 35, 37, 38, 40, 46, 47).

The effects of these nonideal factors on the performance of air cleaners can manifest themselves in either of two directions: (a) The air cleaner can be more effective than it would be in the ideal case if the concentration of contaminants in the air that reaches it is higher than the average level in the building. Such a condition represents, in effect, a partial approach to source exclusion. (b) The air cleaner can be less effective than it would be in the ideal case if the concentration of contaminants in the air that reaches it is less than the average level in the building. Such a condition represents, in effect, a partial "short-circuiting" of the treated air back into the air cleaner before it is thoroughly mixed in the indoor space.

Not all air cleaning devices are suitable for indoor applications. Some are too noisy, some occupy too much space, some generate too much heat, and some produce contaminants that do not decay rapidly enough. Furthermore, the capital and operating costs of all such devices must be considered to be competitive with the cost of an equivalent rate of ventilation. Ultimately, of course, both control approaches must be weighted in terms of the value of health benefits gained.

The following outline will categorize air cleaners according to their applicability either to particulate or to gaseous contaminants, and will identify those that are unsuitable for indoor applications.

Air Cleaners for Particulate Matter

Mechanical filters
Electrostatic precipitators
Inertial separators (cyclones)
Settling chambers
Scrubbers

Of these, the last three are generally unsuitable for nonindustrial environments because they occupy too much space for the throughput of contaminants to which they would be exposed in indoor environments. Inertial separators and scrubbers are frequently used for industrial applications, but require too much power to be practical for noncommercial uses.

Air Cleaners for Gaseous Contaminants

Adsorbents with chemical impregnations
Incinerators (flame or catalytic)
Scrubbers
Ozonizers

Of these, the last three are generally inapplicable to noncommercial environments--scrubbers for the reasons mentioned above, incinerators because they require and release too much heat, and ozonizers because ozone is toxic.

An adsorbent often chosen for indoor air cleaning appears to be activated carbon. The reason for this selection of carbon in preference to all oxygen-containing adsorbents, such as silica gel, activated alumina, or surface-active clays, is that oxygenated adsorbents are strongly polar. Therefore, unlike carbon, they bind and hold moisture and, in such condition, lose much of their effectiveness for adsorbing organic substances. Carbon, too, adsorbs water from humid air, but this moisture is displaced as the surface and pores of the carbon become loaded with organic matter.

The manufacturing and utilization of activated carbon as an air cleaner is a well established technology. For indoor application, carbon granules (diameter ∿1 to 5 mm) are packed into thin (∿2 cm) beds. Good design of the adsorber makes it possible to achieve high air cleaning efficiency (∿95 percent) with small pressure drop for reasonable air flow (∿5000 N/m^2 per m of bed depth at a linear flow rate of ∿25 cm/s). However, as the carbon saturates, its effective bed depth becomes thinner. Various problems associated with this progressive saturation will be discussed under "research needs."

The restriction to activated carbon does not apply to adsorbents with chemical impregnation. In fact, for those reactions that require aqueous media (reactions involving ionic pathways) polar adsorbents may be preferable because of the water they retain. The most widely used polar adsorbent for such applications is activated alumina. Table 3 lists various adsorbent impregnations and their applications.

STATE OF THE ART IN SOURCE REMOVAL AND EXCLUSION

Source removal and exclusion, as the terms imply, are applied to the pollutant source to prevent entry of the pollutant to the indoor air space. Examples include sealing of basements and foundations to prevent infiltration of radon; the removal of materials, equipment, and products that emit pollutants; and the removal of exterior sources that are in the proximity of occupied indoor spaces.

Table 3. Adsorption

Adsorbent	Impregnant	Pollutant	Action
Activated carbon	Bromine	Ethylene; other alkenes	Conversion to dibromide, which remains on carbon
	Lead acetate	H_2S	Conversion to PbS
	Phosphoric acid	NH_3 mines	Neutralization
	Sodium silicate	HF	Conversion to fluorosilicates
	Iodine	Mercury	Conversion to HgI_2
	Sulfur	Mercury	Conversion to HgS
	Sodium sulfite	Formaldehyde	Conversion to addition product
	Sodium carbonate or bicarbonate	Acidic vapors	Neutralization
	Oxides of Cu, Cr, V, etc; noble metals (Pd, Pt)	Oxidizable gases, including reduced sulfur compounds such as H_2S, COS, and mercaptans	Catalysis of air oxidation
Activated alumina	Potassium permanganate	Easily oxidizable gases, especially formaldehyde	Oxidation
	Sodium carbonate or bicarbonate	Acidic gases	Neutralization

Many controls in the work environment are in the source removal and source exclusion category. The containment of process chemicals to prevent vapor escape is an example. Another is the isolation of a process by barrier walls to minimize worker exposures.

A source removal/exclusion problem of enormous proportions has resulted from the application of asbestos to building interior surfaces for insulation and sound absorption. Although this practice has ended, there are hundreds of thousands of buildings where asbestos has been applied and which are potential sources of airborne asbestos as the material deteriorates or its surfaces are disturbed. Of particular concern are the many applications of asbestos in school buildings.

Asbestos in buildings may be sealed (temporary solution) by coating or impregnating it with certain materials, or it may be removed (permanent solution) and permanently contained elsewhere. Both techniques suffer from many potential difficulties that may result in the escape of asbestos. Although research is underway in identifying usable sealants and in developing removal methods, much remains to be done in the development of safe and reliable techniques.

A source-exclusion problem of increasing significance is that of radon, a radioactive gas that occurs naturally in rocks and soils, and that may also occur in building materials derived from rock, such as concrete. The greatest concern is in areas where source materials such as uranium and radium are present in significant amounts near the surface. Unless excluded, radon gas may permeate building foundations, accumulating in indoor air. Since radon gas is short-lived, the alpha-emitting, electrically-charged radon daughters are the contaminants of greatest concern.

Several radon exclusion techniques are being evaluated, particularly in Canada and Florida. Techniques reported successful by Canadian researchers include finding and plugging holes and cracks in concrete foundations, membrane sealing of porous surfaces, and subfloor venting and ventilation. These source-exclusion techniques may be augmented by containment removal techniques such as indoor air filters and precipitators, which extract the respirable particulates to which the charged radon progeny attach, and ventilation of the indoor air space using air-to-air heat exchangers.

Most other source removal and exclusion techniques have resulted from (a) complaints of nuisance or discomfort, or (b) from findings regarding the safety of consumer products. Formaldehyde emissions from urea formaldehyde from insulation and from particle board have caused both complaints from building occupants and perceptible health effects. The material has had to be removed in some cases and several sealing methods have been tried with varying success. Asbestos-containing hair dryers and fluorocarbon-containing aerosol sprays are examples of products being removed from the marketplace because of research findings in the environmental safety area.

Source removal is, of course, the most effective way to control a pollutant. Source exclusion has the drawback of potential failure of the barrier through accidental rupture, deterioration, deliberate or unintentional breaching of the system, etc. Both methods, however, should be prime considerations in any indoor air quality control strategy.

STATE OF THE ART IN PRODUCT SUBSTITUTION

Product substitution can be as effective as simple source removal where a product emits an indoor air contaminant. The principal reservation to product substitution is the potential of replacement product to also emit contaminants or to be harmful in some other way.

Examples of product substitution include nonfluorocarbon propellants to replace fluorocarbons in aerosol sprays, solid deodorant sticks to replace sprays, various types of bug killers to replace many found hazardous, water-based finishes to replace those containing volatile organic solvents, and mineral insulation (or others) to replace urea-formaldehyde.

It is difficult to recommend a program directed at product substitution because of the nature of the occurrence of amenable problems. Each occurrence is product-specific and depends upon discovery to spur development of substitutes. One aspect that must be emphasized, however, is the need for evaluation of the hazard potential of the replacement. History has demonstrated that the replacement is sometimes more damaging than the original product.

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Section 3

RECOGNIZED AREAS OF OMISSION

SCOPE OF INDOOR AIR PROBLEM

The Control Technology Group concentrated on the residential environment relative to nonresidential, nonindustrial environments. The industrial environment was not addressed significantly. Because the general public has less control of nonresidential indoor environments to which it is exposed, it could be exposed to a greater risk in these environments. The group feels strongly that this large sector of the built environment not be omitted from research plans.

PRODUCT SUBSTITUTION

The Control Technology Group did not deal significantly with the product substitution area. One of the reasons was a lack of time to adequately address the subject. Another, perhaps more important, reason was that the group felt that the product substitution area was one that is product-specific with each offending product demanding a unique approach to finding an adequate replacement. This area is, perhaps, less a government function than one for industry.

Section 4

RESEARCH NEEDS

GENERAL PROBLEM DEFINITION NEEDS

Although indoor air pollution control methods should be studied in parallel with other indoor pollution research, there are a number of areas where controls research would be greatly aided by further developments in the areas of instrumentation, monitoring techniques, pollutant characterization, health effects and risk analysis. For instance, a ventilation standard will not be definitive until the health risk associated with specific pollutant concentrations have been determined. The following is a list of some of these general research needs that controls research will depend on:

1. Identification of the pollutants of concern
2. Determination of the concentrations to which these pollutants need to be lowered
3. Characterization of the pollutants including:
    - Source identification
    - Source emission mechanisms and rates
    - Chemical and physical interactions/transformations
    - Transport and removal mechanisms
    - Measurement methodology
4. Development of models for air and contaminant movement within buildings.

Evaluation Methodology Needs

A method of evaluating and deciding between various control strategies needs to be agreed upon. This method should take into account the following points:

1. Technical effectiveness
    - Laboratory and field studies
2. Consumer acceptability
    - Lifestyle effects
    - Reliability
    - Maintenance requirements
    - Hazards from use

3. Commercial availability

   - Manufacturing/marketing capabilities
   - Installation
   - Maintenance

4. Cost-benefit analysis

   - Application to control of other pollutants
   - Initial, operating and maintenance costs
   - Benefit of mitigation of health effects.

CONTROL TECHNOLOGY RESEARCH NEEDS

Indoor air quality research is underway to some extent in all areas--characterization, health effects, risk analysis, controls and monitoring methods, and instrumentation. With the exception of industrial hygiene studies, most research efforts have not been oriented toward specific indoor air quality goals, but rather have been undertaken to show the existence of a problem. The research has established that some pollutants can accumulate in indoor air to concentrations that exceed workplace and/or ambient standards.

The limited research in control technology has been largely directed at controlling indoor exposures of asbestos, radon and radon daughters, and formaldehyde. Several strategies have been considered for these pollutants. Source removal and covering with sealants (source exclusion) have been employed to control asbestos in schools. Sealant covering may be only a temporary solution, but source removal is expensive and time-consuming and may present severe exposure problems during the removal process. Source removal, source substitution, and masking have been considered for indoor formaldehyde control. Research for controlling indoor radon and radon daughters has been principally directed at source exclusion, electronic air filters, and ventilation. Air-to-air heat exchanger ventilators appear to be effective dilution devices for reducing radon and other pollutant concentrations.

Ventilation Research Needs

The following research needs apply, in most cases, to all building types. The needs have been organized into generic measurements followed by the categories of ventilation systems.

Ventilation Rate and Pollutant Measurement

- Develop and verify the accuracy of an inexpensive method of measuring the average ventilation rate in a home over periods ranging from 1 week to 1 year.

- Develop an accurate model of infiltration rate versus weather conditions based on a simple measurement, and/or building type.

- Determine the ventilation rate (infiltration, natural ventilation, and mechanical ventilation) and the concentration of the pollutants of concern in a statistically significant number of U.S. homes and other buildings over at least month-long periods during different seasons of the year. Correlate this information with building type, air tightness level, general weather conditions, heating and cooling system type and energy usage.

- Develop air and contaminant movement models for residences.

Natural Ventilation

- Determine the effects of window opening frequency, amount and duration on ventilation rate, pollutant concentration, and energy usage.

FORCED VENTILATION

General

- Determine the acceptability to building occupants of the various types of mechanical ventilation systems, considering: first cost, noise, discomfort, energy savings, pollution control.

- Determine of mechanical ventilation systems can be operated intermittently during periods of severe outdoor weather conditions and still be effective at reducing pollutant concentrations.

- Determine if an extensive distribution system is necessary for a residential mechanical ventilation system or whether pollutants can be controlled by just exhausting and supplying air to one area of the house.

- Determine if ventilation rates can be varied either manually or by automatic control to take into account the decay in the source strength of certain pollutants with time. If an automatic control system is used, what pollutant should the system be based on?

- Determine impact of different tyeps of heating systems on the necessary ventilation rate and examine solutions to the problem of inadequate combustion air supply in buildings where infiltrtion has been reduced.

- Evaluate methods for the control of pathways for contaminant transmission to building occupants, e.g., examine the need for pressure control to prevent cross contamination, consider the location of air intakes and exhaust, and examine air flow around buildings.

- Determine if spot ventilation at a pollutant source, such as using a range hood over a gas stove or ventilating a basement directly if the basement is the source of radon, is more cost-effective and more effective in pollution reduction than whole-house ventilation.

- Determine if combining spot ventilation with a heat exchanger is cost effective.

- Determine if a spot ventilator, such as a range hood, can be used for whole house ventilation.

Air-to-Air Heat Exchangers

- Determine effectiveness versus flow rate at various operating conditions (i.e., dry, condensing, and freezing) for commercially available residential units.

- Determine mass transfer for both water vapor and pollutants.

- Determine if any pollutants are given off by the materials that make up the heat exchanger.

- Test the heat transfer and mass transfer effectiveness of commerically available units that have operated in the field for at least 1 year to determine degradation versus time.

- Model heat exchanger heat transfer.

- Perform corrosion durability and fire testing.

- Determine the stability of airstream flow rates through the heat exchanger and the effect of instabilities on the energy consumed to condition ventilation air.

- Determine the effectiveness of ventilation systems with heat exchangers in reducing pollution and saving energy when compared to other ventilation systems without heat recovery.

- Determine the cost-effectiveness of ventilation systems with heat recovery versus climate and ventilation rate when compared with a simple exhaust ventilation system.

- When are heat exchangers economical in a retrofit situation?

- When is the recovery of latent heat desirable in a residential system?

- Should a ventilation system with heat recovery be combined with a forced air furnace system or should the units be separate?

Contaminant Removal Research Needs

Carbon adsorption offers a significant potential in removing contaminants from indoor air. Research needs are associated with the following characteristics of these devices:

1. Their saturation is not signalled by a change in color, resistance to air flow, or total mass.

2. Adsorption efficiency is sensitive to ambient temperature and humidity, to the extent of saturation of the adsorbent, and to the nature and concentration of the contaminants.

3. As the carbon approaches saturation, some previously adsorbed contaminants are desorbed.

4. The carbon surface is catalytic, and can promote reactions among adsorbed molecules, including oxidation and hydrolysis.

5. Saturated carbon cannot be effectively reactivated by the heating or washing methods available to the householder or to maintenance workers in commercial buildings.

6. To a first approximation, the effect of activated carbon for physical adsorption of gases in ventilating systems depends on the increment of molecular weight of the contaminant gas over that of air. Therefore gases of low molecular weight, such as formaldehyde and ammonia, are not effectively adsorbed.

The following set of research needs is based upon the above-listed characteristics of carbon adsorption:

- Develop standardized methods for evaluating the degree of saturation of a partially saturated adsorber.

- Develop data base for expected service life of adsorbers.
- Develop end-of-service-life indicator for carbon air cleaners.
- Evaluate the patterns of carbon saturation with particular reference to fractionation and chemical conversions that can occur on the carbon surface and can influence the quality of the post-carbon air.
- Develop range hoods which are effective for removal as opposed to dilution; also reduce noise level.
- Develop more effective adsorption technique.
- Develop effective impregnation for activated carbon.
- Develop more effective filter media.

A variety of additional research needs in the area of contaminant removal have been suggested. Some of these are similar to those listed specifically above for carbon:

- Develop strategies for use of filters of various media for forced air systems.
- Develop end-of-service indicators for various types of air cleaners.
- Determine particle size efficiency and useful life of particulate filters.
- Study applications of electrostatic fields for removal of particulate contaminants.
- Investigate potential for technology transfer of air cleaning mechanisms from industrial and military applications.
- Study contaminant removal in energy storage devices.
- Study the application of climate control for control of pollutants, for example, formaldehyde versus humidity.
- Study the effectiveness of using independent filtering systems on the return and the makeup air.
- Study the relationship between greenhouse plants and indoor air quality.
- Investigate models for natural sinks and ways in which they might be enhanced.

Source Removal/Exclusion Research Needs

The research needs listed here are directed at finding methods to prevent the entry of contaminants to indoor space so that dilution and air cleaning systems will not be required:

- Identify sources and source strengths (i.e., emission rates). Emission rates may be influenced by ambient conditions and time of emission.

- Develop techniques for establishing material standards based on emissions. The Institute of Hygiene - Denmark has done some work in developing this type of standard. Emission testing standards also require development.

- Develop models for building materials based on emission rates. Some pollutants to be considered are radon/daughters, plastics and plasticizers, formaldehydes, rubber, paint (e.g., mercury), combined materials.

- Control strategies for removal of sources, including synergistic emission rates or synergisms from different emissions, should be identified and evaluated.

- Determine inventory of coatings and encapsulating compounds which can intervene or retard emission rates. Safety factors (i.e., emissions from the encapsulating compounds) must be considered.

- Determine alternative control strategies for eliminating combustion products (e.g., substitution for standing pilots).

- Determine total characterization of indoor spaces which may be used to:

  - Model effectiveness of control strategies
  - Match control strategy to types of emissions.

- Develop building technologies which will exclude soil gas, pesticides, etc. Also develop reliable remedial techniques.

- Determine inventory of emission rates/fates for consumer products:

  - Appliances and equipment (heating, cooking, etc.)
  - Solvents and chemical specialties
  - Home furnishings.

- Identify occupant activities (i.e., human factors) which can be considered as control strategies for source removal/exclusion.
- Determine inventory of emission rates/fates from processes:
  - Cooking
  - Use of copy machines, etc.
- Map and compile inventory of hazardous building site areas relative to ambient emissions, such as radon.

Product Substitution Research Needs

The Control Technology Group participants did not identify specific research areas, at least in any formal way, that should be addressed in the product substitution area. The discussion brought forth several ideas, however, that are summarized as follows:

- Perhaps research should be undertaken to identify and label products that emit contaminants.
- Perhaps ingredient labeling is needed.
- A standard outgassing test is needed.
- A list of criteria for cost-benefit analysis is needed.
- Perhaps tests under the Toxic Substances Control Act are needed.
- What do we do about UF foam? Mineral wool can substitute.
- What do we do with retrofit versus new buildings?
- How can we detoxify or remove existing materials?
- Identify materials that should be banned.
- Changing building materials requires massive economic changes, because materials are made in very large quantities.
- Copying machine emissions are an example among many others.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The findings of the Control Technology Group of the Workshop on Indoor Air Quality Research Needs can be summarized as follows:

1. Ventilation is a centuries-old technology that has been used for increasing human environmental comfort, significantly recognized only as controverting energy conservation objectives.
2. Contaminant removal technologies have been in use for many years, emphasizing various kinds of filters and adsorbers, mainly in combination with heating and air-conditioning, air-recirculation systems.
3. Source removal and exclusion technologies are relatively new, brought to the fore by recent developments in energy conservation, health effects research discoveries, and chemically-based consumer products. In at least one case, that of radon, the source can only be excluded; it cannot be removed because it is a natural soil emission.
4. Product substitution is a product-specific method of indoor air quality control, not conducive to a generic control development program.
5. There is an unfortunate tendency to view indoor air quality problems as residential, rather than as problems of all types of interior environments.
6. Research to this point has emphasized problem definition, but because the realm is so large, the data base is grossly inadequate.
7. Indoor air quality control technology research is just beginning, spurred by the problems being exacerbated by building energy conservation measures.
8. Control technology devices and regulations are likely to be imposed upon suppliers of consumer products and building materials, but not upon building occupants; use by occupants will remain optional.
9. Heating/air-conditioning and cooking equipment manufacturers, home builders, utilities, and building products manufacturers are especially interested in indoor air environmental developments because of the potential economic effects upon them.

RECOMMENDATIONS

The Control Technology Group of the Workshop on Indoor Air Quality recommends that the Interagency Research Group on Indoor Air Quality undertake to do the following:

1. In developing a coordinated national program for indoor air quality research, specifically providing for communication between researchers and public users, involve the private sector in research planning, and conduct indoor air research outside the residential environment.

2. Design a research program that includes addressing the research needs outlined in this document.

3. Integrate that research program into the "National Plan," assigning responsibilities for specific research to specific Agencies with recommended funding.

4. Continue, as an ongoing responsibility, the updating of the Indoor Air Quality Research Inventory as a valuable input to an evolving program.

5. Continue, on a periodic or as-needed basis, the convening of workships and broadening the base of technical input to facilitate a coordianted, dynamic, results-oriented research effort.

6. Ensure that all indoor air environments are addressed and afforded the research necessary to resolve air quality problems within them; this means addressing residential and all the various subtypes of nonresidential building environments.

RISK ANALYSIS

INDOOR AIR QUALITY RESEARCH STRATEGY

Nathaniel F. Barr

REPORT ON THE PANEL ON RISK ANALYSIS

The panel expressed agreement with the objectives of and strategy for health risk analysis developed by the Interagency Research Group (Table 1), and with the comments of the Risk Analysis Working Group on the inventory of current research and the Draft Indoor Air Quality Research Strategy (Table 2).

The consensus of the panel was that the discipline of conducting analyses of current knowledge and uncertainties regarding the health effects of indoor air pollution could lead to improved perspective on and sharpen the definition of research requirements.

The panel approved the level and scope of the risk analysis recommendations by the work group. These recommendations are presented in Table 4.

The panel and audience identified and extensively discussed several cautions to be observed in the conduct and utilization of health risk analyses. These were:

1. There would be a very wide range of uncertainty associated with health risk estimates derived from the current data base.
2. The use of results of health risk analysis for purposes other than R&D planning (i.e., policy formulation, regulation and public information) should be approached with extreme caution.
3. The scope of health risk analysis should be broad enough to provide perspective on factors such as the health implications of inadequate housing and other safety features of the indoor environment.
4. It is suggested that results of ongoing risk analysis be provided to participants in advance of future workshops and discussions of these analyses be scheduled early in the agenda.

A Risk Analysis study presented by Dr. Anthony Nero is included as an example of such scientific work.

Table 1. Objectives and Strategy for Health Risk Analysis

Objective

The objective of health risk analysis is to strengthen the basis for planning and conducting research and development programs by analyzing current knowledge and uncertainty regarding the potential health consequences of indoor air pollutants.

Strategy

This objective will be accomplished by establishing 4 to 6 groups to gather, review and analyze, in a continuous manner, existing knowledge and the results of ongoing research. These groups will provide analytical descriptions of knowledge and uncertainty regarding the potential health impacts of indoor air pollutants and of technologies that generate indoor air pollutants.

Each group will operate at a level from 2 to 5 person-years per year (py/y) and issue annually a report which identifies potential health impacts and analyses of what is known and not known regarding impacts.

Table 2. Working Group Comments on Inventory of Current Research and the Draft Research Strategy Plan

I. Comment on Inventory of Current Federal Research and Development to Indoor Air Pollutants (Table 3)

The Risk Analysis Working Group was unable to identify any projects listed in the inventory of current Federal Research and Development that are devoted to the analysis of potential health risks of specific indoor air pollutants or of specific technologies which produce indoor air pollutants.

II. Comment on Draft Indoor Air Quality Research Strategy Plan (IAQRSP)

The Working Group notes the IAQRSP does not include projects which would undertake to assess the potential health impacts of indoor air pollutants or of technologies, programs and/or policies that would modify indoor air pollutants.

Table 3. Status of Risk Analysis on Indoor Air Pollutants

Agency	Substance	Health Effects	Sources Evaluated	Exposure Analysis	Risk Analysis	Status	Comments
EPA/CAG	Formaldehyde	Cancer	Unspecified	Unspecified		Completed Nov. 1979	
CPSC	Formaldehyde	Chronic Health Effects Using CIIT Data	Unspecified	Unspecified		Forthcoming	
CPSC	Formaldehyde	All adverse effects	Urea formaldehyde foam	Unspecified		Forthcoming	
CPSC/EPA/IRLG	Formaldehyde	All adverse effects	All sources	Unspecified		Forthcoming	
EPA/TSCA	Asbestos	Lung Cancer	Friable asbestos-containing materials in schools	School children, teachers and other school personnel		Completed Sept. 1980	
USEPA/ORP	Radon and Radon Progeny	Lung cancer Other cancers				Computer	Testing of health effects models to determine sensitivity to perturbations of input assumptions and parameters
EPA/ORP	Radon and Radon Progeny	Lung Cancer Other Cancers	Uranium miners	Average 85 WLM		Papers in preparation	Through contract.

Table 4. Recommendation for Health Risk Analysis Research

Research Area	Research Subarea	Priority	Rank	Recommended Project Description	Duration	Funding Level	Agency
Risk Analysis	Technology Analysis						
	-Building Energy Conservation			Initiate analysis of potential risks to human health of building energy conservation programs	Continuous	3 to 5 py/y	
	Gas and electric stoves			Initiate analysis of potential risks to human health of using gas and electric stoves for cooking	Continuous	3 py/y	
	-Wood burning stoves			Initiate program to extend current analysis of the potential health impacts of wood burning for residential space heating	Continuous	2 py/y	
	- Radon			Expand current analysis of risks to human health of radon in the indoor atmosphere.	continuous	2py/y	
	- Formaldehyde			Continue current analysis of potential risks to human health of formaldehyde in the indoor environment.	continuous	3py/y	
	- Hydrocarbons			Initiate an analysis of the potential risks to human health of hydrocarbons in the indoor environment.	continuous	3py/y	
	- Pathogenic Organisms			Initiate an analysis of the potential risks to human health of pathogenic organisms in the indoor environment.	continuous	3py/y	
	- Particles			Initiate an analysis of the potential risks to human health of particles in the indoor environment.	continuous	3py/y	
	- Carbon Monoxide			Initiate an analysis of the potential risks to human health of carbon monoxide in the indoor environment.	continuous	3py/y	

RISK ANALYSIS TO RADON AND RADON PROGENY

by

Anthony V. Nero, Jr.

INDOOR AIR QUALITY HEALTH RISK ANALYSIS*

Anthony V. Nero, Jr.

The purpose of this talk is to demonstrate briefly some of the principal considerations in performing indoor air quality (IAQ) health risk analysis. I will indicate these considerations generally and, in addition, use the case of radon and its daughters as an example. Discussion of this case will effectively constitute an extension of the session on radon. However, this shouldn't be taken to imply that radon is necessarily the main pollutant of concern. It is merely the one we will use to demonstrate the principles of risk assessment for indoor air pollutants.

Just to indicate where we might be going, there are two major questions we can ask ourselves in the area of IAQ risk assessment. One is the question of what the current risk is; i.e., the risk from present indoor exposures to air pollutants. The second question, which can be distinguished from the first, is what change in the net risk can be expected from a particular change in the current situation; e.g., a strategy for saving energy or improving air quality in housing.

In trying to examine current risk or changes in it, an array of different pollutants have to be considered. There are several categories into which we can place these different pollutants. I list several categories that arise fairly naturally: smoking products; combustion emissions, which may be considered to include those from smoking; organics, such as formaldehyde, but including all sorts of other materials; radon and its daughters; bacteria; and others that I haven't listed here, simply because I've only included the most familiar categories.

In terms of a health risk assessment, there are several risk categories or health end points that one might examine. Again, I list several classes only as examples. One general class of effects includes respiratory irritation or disease; lung cancer, of course, is a member of this class, but I've singled this out because I will treat it explicitly as we proceed. There are other classes of effects; e.g., acute syndromes associated with carbon monoxide exposures (even leading to death), formaldehyde exposures, and so on. But, in addition to these specifically "health" effects, there is a more general class of "environmental" effects. Some of these effects are those that are ordinarily noted by house occupants; i.e., general comfort parameters, odors, etc. There are, in addition, all sorts of other effects, including direct or indirect effects that might occur outdoors. I'll point out later how these arise as part of risk assessment.

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* Edited transcript of talk given at session on risk assessment.

Let me turn first to the problem of assessing the current risk from radon daughters, just as an example of the assessment process. In order to assess the risk, several kinds of information are needed. One clearly needs information on exposures, and even this is divided into two kinds of information as I frame it here. The first is data on average exposures, and the second is information on the distribution of exposures; i.e., how many people are getting exposures of various sizes. In order to understand this distribution, one has to have information on concentrations of pollutants, in this case the radon daughters; one also has to have information on patterns with which people use their houses or are present in their houses.

I should make two comments in passing that I'll elaborate on in a few minutes. One is that the average exposure is not known to be better than about a factor of 2. One can argue about the precise uncertainty, but I'll use this factor in what follows, indicating where it comes from. A second point that I would make is that the exposure distribution is not known well at all. For example, the question of how many people are receiving exposures above any specific level cannot be answered with any certainty. We cannot characterize exposures adequately either on the basis of direct measurements of concentrations or on the basis of an understanding of what the sources of radon are and how radon gets into buildings - we don't have that information, nor do we know much about the behavior of radon daughters indoors. So our information base on daughter exposures is not very good. However, unlike other indoor air pollutants, radon information is still good enough to make rough estimates of the kind I'll indicate below.

The second class of information required for risk assessment is what the health effects of a given exposure are. This information was discussed in a fair amount of detail by William Ellett, in the session on radon, so that I will not discuss the basis of the dose-response information that we have. However, as I go along I'll use some of that information, as you'll see. In any case the range of uncertainty is large - about a factor of 10 from low estimates to high - or a factor of 3 around the geometric mean. Now, in using such information, it is very important to remember that there are two kinds of health risk estimates that one might make. First is an estimate of the total population risk, which information can be used for certain purposes. A second kind of estimate that one could make is what the risk is to those who are exposed to relatively large concentrations. These people are at the highest risk, and one might want to devote more attention to them than to people who are at lower risk.

Let us turn now to actually making a risk estimate, beginning with the question of what the average concentrations might be. I show you a large table, not so that you should remember the specific data, but merely to indicate what the state of information is. The total number of houses in which radon or radon daughter concentrations have been measured in this country is of the order of hundreds. Most of these arise from studies in which 10 to 100 houses were monitored. There have actually been more studies than indicated in the table, because I've excluded studies of only one or two houses and generally speaking I have only included studies that had about 10 or more houses. In any case, the information base is not very large and, because the distribution of exposures is very large. we don't really have much information about either the average or the distributions.

However, I suggest in the next figure that we do have some information, although the figure must be taken only as suggestive. This curve is only schematic and is not an attempt to represent the actual data. Nevertheless, we could say that a typical concentration of radon daughters, given in the usual units; i.e., working level (WL), is probably on the order of 0.005 WL. I emphasize the word "typical." The average concentration in houses is probably not far from that number. It could be virtually anywhere in the range between 0.001 (or 0.002) and 0.01 WL. So I've written down that the average concentration is about 0.003 WL, with an uncertainty factor of 3.

Another question of substantial interest is what highly exposed individuals might be encountering. What I've indicated both by the tail that extends very far out, far above the average of the distribution, and by the number that I've cited, is that there are probably some people in the United States who are exposed routinely to concentrations of the order of 0.05 WL - a factor of 10 above the average. However, we don't know how many people they are. It would be interesting to know.

Given information on concentrations, we can calculate a typical exposure, which I've written down in the usual unit, working level months (WLM), the definition of which isn't needed to follow the discussion. But in terms of this unit, the average exposure could be about 0.15 WLM per year and the "maximally exposed" individuals we have just mentioned would be receiving a factor of 10 greater exposure than this.

Knowing these exposures and the kind of dose-response information presented at the radon session, we can make an estimate of the risk from indoor radon. From the data discussed in that session (see Table 2), we can see that the dose-response factor, assuming a linear dependence of effect on dose, has been estimated by various entities to have values ranging over a factor of 10. Each one of those estimates itself has, of course, some uncertainty. But loosely speaking, we might say that we know the dose-response factor to within a factor of 3 about some mean. I've written down the dose-response coefficient as 300 cases per million WLM exposure among a population; the usual unit is "person-WLM."

Using this dose-response factor, together with exposure information, we can make a risk estimate. What we obtain from the values indicated is a radon-daughter induced lung-cancer incidence of approximately 45 cases per million people per year among the U.S. population. But the range is large because of the factors of 3 uncertainty in exposures and dose-response. What the overall uncertainty is depends on how these factors of 3 are folded together. One purely statistical approach would yield, overall, a factor of 5 in either direction. On the other hand, the extremes yield a factor of 9 in either direction. Taking the first approach, the estimated average risk among the U.S. population is 9 to 225 cases per million per year.

We would get a somewhat different number for the individual risk of those who are exposed continuously to an exposure of 0.05 WL, the number we cited earlier for those at higher risk. Estimating the risk of an individual living in that concentration for a lifetime, based on our dose-response factor, yields the result that such an individual has an added lifetime chance of getting lung cancer of about 4 percent. Now again, the uncertainty in the dose-response factor, a factor of 3 in either direction, would cause us to modify this to about 1 to 10 percent. This is a very large risk.

This is the kind of procedure one could go through in examining this particular facet of current indoor air quality risks. If we look at the mean radon-related lung cancer incidence that I have written down, 45 cases per million per year, this turns out to be very close to the lung cancer incidence among those who don't smoke; roughly within a factor of 2. The uncertainty in this radon-related estimate is of course large. Increasing it by a factor of 5 to 225 cases per million per year (the estimate associated with the upper end of the uncertainty range) yields an estimate that exceeds the observed lung cancer incidence among nonsmokers. If we take the other end of the range of risk estimates, 9 per million per year, we obtain a much smaller number. But it is still more than a thousand lung cancer cases per year in the United States. This is significant.

Let us now go on to the next major point. If we understand what the current risk is from current exposures to radon or other indoor pollutants, how do we understand the health effects of a change in the building stock. Such a change could be due either to an interest in energy conservation or to an interest in indoor air quality. In either case we would like to know what the net change in the risk would be. There are several possible sources for a change in the risk. It is possible to change the source strength of the individual pollutants; it is possible, by implementing energy conservation or indoor air quality measures, to change the infiltration or ventilation rate; it is possible to clean the air actively. Any of these changes could effect a change in the net risk.

There are several broad considerations that have to be kept in mind. There are, in fact, many indoor air pollutants. For each of them, we would need exposure information and dose response information. In effecting a change, for example a change in energy use in buildings, we would not only change indoor concentrations; we would also change outdoor exposures to some pollutants. These pollutants could come from the individual houses, from energy production facilities that supply energy to those houses, and so on. I'll explain this further in a moment.

As I stressed, we are interested, in questions of population average both exposures or risks and of individual risks. Moreover, just to emphasize a point that is obvious to anyone who has been looking at risk assessment, a great danger is to emphasize those parts of the risk that we are able to quantify and to ignore those that we aren't able to quantify, even when the latter are comparable in importance, or even more important.

As I've said, one of the possible factors that might cause a change in indoor air quality risks is the implementation of measures to save energy. In order to understand the change in net risk from a saving of energy, we have to consider both the effect on indoor air quality and other effects. In fact, we have to look at the entire energy system that supplies the energy for, as an example, space heating and cooling. I don't want to explore this in detail, but merely to indicate through a rather complex figure the kind of things we might consider. I've tried to indicate on the left the energy supply technologies and, on the right, the points of use of different energy supplies. In considering energy use for space heating and cooling, the end uses are at the lower right. But in order to consider the net effect of a change in end use, we have to look at the effect on the entire system. Let me just indicate what this means in another way, using a simpler figure indicating classes of envi-romental effects. In a house one has what we could call "internal" risks due to exposures indoors. One would also induce "external" risks; for example, burning oil, gas, or anything else (wood?) in the house that results in emission of pollutants into the (outdoor) air. This can affect people outside the house. In addition, if energy is supplied from some centralized energy technology, there are risks associated with using that technology, including what I call external risks; i.e., risks due to emissions into the external environment, and also occupational risks that are internal to that technology. These may appear to be obvious things, but it is important that they not be neglected when performing an assessment aimed at estimating changes in the net risk.

Finally, let us return to the case of a change in the infiltration rate, considering in particular the effect on radon daughter exposures. The effect of a change in infiltration rate on radon daughter exposures is itself not simple, depending as it does on how the change is brought about and on what control technologies are associated with it. In addition, any complete risk analysis would have to include other indoor pollutants, some of which are identified, but many of which have not yet been associated quantitatively with risks. Moreover, the externalities that I have referred to would have to be considered.

For the case of indoor radon, let me just indicate two key points. First, by changing the infiltration rate, we can have a highly variable effect on radon daughter concentrations, depending on how that change is accomplished. I show some data from a house in Maryland in which the ventilation rate was controlled by use of a mechanical ventilation system with an air-to-air heat exchanger. The upper figure shows the variation in the radon concentration as a function of time over a 2-week period. During that 2-week period, the ventilation rate was maintained at about five different values. The equilibrium radon concentration corresponds pretty well, as we would expect, to the inverse of the ventilation rate. However, the daughter concentration, which is shown on the lower figure, is much more complicated. A variety of different kinds of mechanisms can remove daughters, including not only ventilation but also filtration and adhesion to various surfaces in the house and the air circulation system. The point is that predicting the effect of a particular change in the building stock on radon daughter exposures is not a simple question.

The second point on indoor radon is indicated in the final very schematic figure, which in fact presumes we know something about the effect of ventilation rate reduction. What I want to indicate conceptually is the kind of trends we might expect from different strategies beginning now, i.e., in the year 1980. What I've tried to plot schematically is the average population exposure to radon daughters over a period extending from the year 1900 through 1980 to some time in the future. What I've suggested in the figure is that there has probably been a modest increase in radon daughter exposures during this century. This presumption, based not on experimental evidence, but on conjecture, assumes some decrease in infiltration rate from tightening of houses over the years.

Whether or not this has actually occurred, the present point of interest is what might happen in the future, say for the next 20 years and beyond. Changing the housing stock is a relatively slow process. Considering the energy-saving measures that might be employed in existing houses and the related practices that might be employed in building new housing, I suggest that if we employed no explicit control concepts or specific control technologies, radon daughter exposures could increase by about 25 percent over the next 20 years. Taking this conjecture for the sake of argument, we can consider what else might happen. If we give some explicit attention to the question of radon exposures, e.g., if we try to identify those areas or individuals that have particularly high exposure, we could effectively cut the tail off the exposure distribution that I showed you, eliminating much of the risk to the highly exposed portion of the population. Moreover, if we also employ control technologies in very tight houses, we would be avoiding a large amount of associated exposures. With such attention, we could hold radon daughter exposures below the trend of the last century or so, and even decrease average exposures. These are, of course, just two examples of what might happen.

I close by summarizing what we have been talking about: broadly speaking, the role of indoor air quality risk assessment. One purpose is to quantify the current risk, both to identify problems that we don't understand very well and as a basis for understanding what research might be done to improve our information base. A related interest is to indicate the need for development of control technologies. The other purpose of risk assessment is to understand the effect of a particular action, whether a program to save energy or a decision to employ a control technology, on the total risk. Such assessment involves the risk both indoors and outdoors, arising both from the end use and from the rest of the energy system. Risk assessment is an important tool for understanding what priorities we might set in trying to increase our information base and doing research relevant to it. It is also important as a tool for understanding the health effect of decisions we might make to change buildings in the United States.

INDOOR HEALTH RISK ASSESSMENT

MAJOR QUESTIONS:

- RISK FROM CURRENT INDOOR EXPOSURES
- CHANGES IN NET RISK FROM VARIOUS STRATEGIES

MAJOR INDOOR POLLUTANTS:

- SMOKING
- COMBUSTION EMISSIONS
- ORGANICS
- RADON
- BACTERIA........?

MAJOR POTENTIAL HEALTH EFFECTS:

- RESPIRATORY IRRITATION OR DISEASE
- ACUTE SYNDROMES, INCLUDING DEATH
- LUNG CANCER

OTHER ENVIRONMENTAL EFFECTS:

- INDOORS - ODORS, COMFORT
- OUTDOORS - INDIRECT EFFECTS

ASSESSING PRESENT RISK FROM RADON DAUGHTERS

EXPOSURE AVERAGE AND DISTRIBUTION:

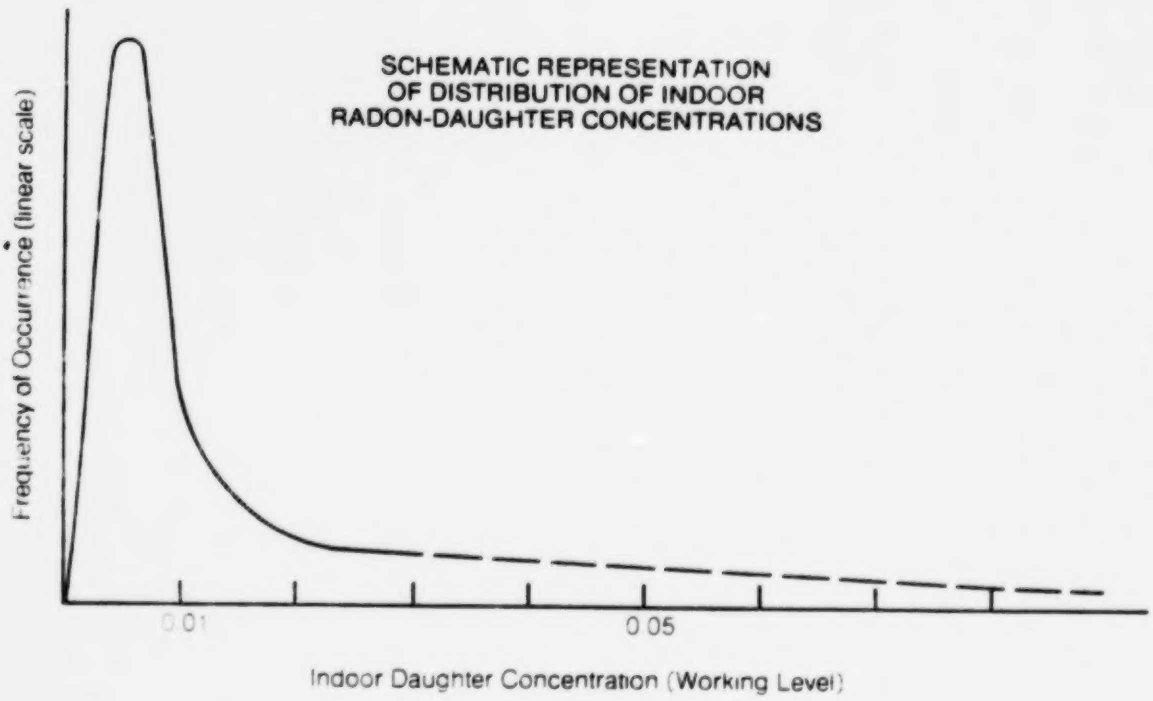
- NEED CONCENTRATIONS AND USE PATTERNS
- AVERAGE NOT KNOWN TO BETTER THAN FACTOR OF 2
- DISTRIBUTION NOT KNOWN AT ALL
- CAN'T YET CHARACTERIZE ON BASIS OF SOURCE STRENGTHS AND BUILDINGS CHARACTERISTICS

DOSE - RESPONSE:

- BASED ON MINERS
- RANGE OF UNCERTAINTY IS LARGE: FACTOR OF 10

ESTIMATING EFFECTS:

- POPULATION RISKS: E.G. AS BASIS FOR BUILDING STRATEGIES
- INDIVIDUAL RISK: E.G. AS BASIS FOR CONCENTRATION LIMITS



SCHEMATIC REPRESENTATION OF DISTRIBUTION OF INDOOR RADON-DAUGHTER CONCENTRATIONS

Average daughter concentration (U.S. housing): $\simeq$0.003 WL (x 1/3 to x 3)

Some incidence of much higher concentrations: $\simeq$0.05 + WL

Average daughter exposure: $\simeq$0.15 WLM/yr (x 1/3 to x 3)

Exposure of those in high concentrations: $\simeq$1.5 + WLM/yr

Dose-response factor: $\simeq$300 lung cancers/10^6 person-WLM (x 1/3 to x 3)

Estimated U.S. lung cancer incidence from
radon daughter exposures: $\simeq$45 cases per million population per year (9 to 225, considering uncertainty of x 1/5 to x 5)

Selected Radon and radon daughter measurements in U.S. residences
(residences are single family except where noted)

Location	Reference	^{222}Rn(nCi/m^3)^a	Daughter PAEC (WL)^a	Number of Residences	Type of Measurement	Comments
ORDINARY AREAS:						
Tennessee	**Lowder 1980**		0.008(0.0008-0.03)	15	Grab	Shale area; mostly concrete construction
Boston	**Yeates 1972**	**0.07(0.005-0.2)**	(up to 0.002)	7	Grab and ventilation	Single family; air exchange rate; 1-6/h
		0.09(0.01-0.2)	(up to 0.002)	3	Grab and ventilation	Multiple family, air exchange rate: 5-9/h
NY/NJ	**George 1978**	**0.8^b(0.3-3.1)**	0.004^b(0.002-0.013)	21	Several integrated measurements over year	17 single family; 3 multiple family; 1 apartment bldg.
Illinois	**Rundo 1979**	(0.3-33)	[0.003 - 0.08]*	22	Grab	Wood-frame construction, unpaved crawl spaces (windows closed)
San Francisco area	**Berk 1980**	**(0.4-0.8)**	[0.001 - 0.002]*	26	Grab and ventilation	Air change rate: 0.02-1.0/h (windows closed)
U.S./Canada	**Hollowell 1980**	**(0.6-22)**	[0.002 - 0.05]*	17	Grab and ventilation	Energy-efficient houses; air change rate: 0.04-1.0/h (windows closed)
SPECIAL AREAS:						
Grand Junction Colorado	**Barnes 1975**		0.006^b	29	Integrated year round	Controls for remedial action program (which has included houses in range 0.02-1 WL)
Florida	**Florida 1978**		0.004	28	Integrated year round	Controls on unmineralized soils
	Guimond 1979		0.004(0.0007-0.014)	26	Integrated year round	Controls on unmineralized soils
	Guimond 197[illegible]		0.014	133	Integrated year round	Houses on reclaimed phosphate lands
Montana: Butte	EPA 1980		0.02	56	Integrated year round	**Intensive mining area**
Anaconda	EPA 1980		0.013	16	Integrated year round	**Intensive mining area**

[a] Individual values are averages; values given in parentheses are ranges. All measurements are in living space; values in basements are typically higher.

[b] Geometric mean.

***Calculated from measured radon concentration assuming 0.5 equilibrium factor.**

9/80 ee

Table 2 (RP80)

Estimated Life Time Risks of Fatal Lung Cancer from Radon Progeny

Estimator	Cases per 10^6 Person WLM	
UNSCEAR	200-450	30-yr. exposure to adults
NRC	360	all ages, 1967 U.S. population
EPA - absolute risk	350	cohort (stationary population)
EPA - relative risk	860	" "
BEIR III	850	" "
Victor Archer - absolute risk	1050	" "
NCRP - absolute risk	130	all ages, 1975 U.S. population

ASSESSING CHANGES IN NET RISK

CAUSES:

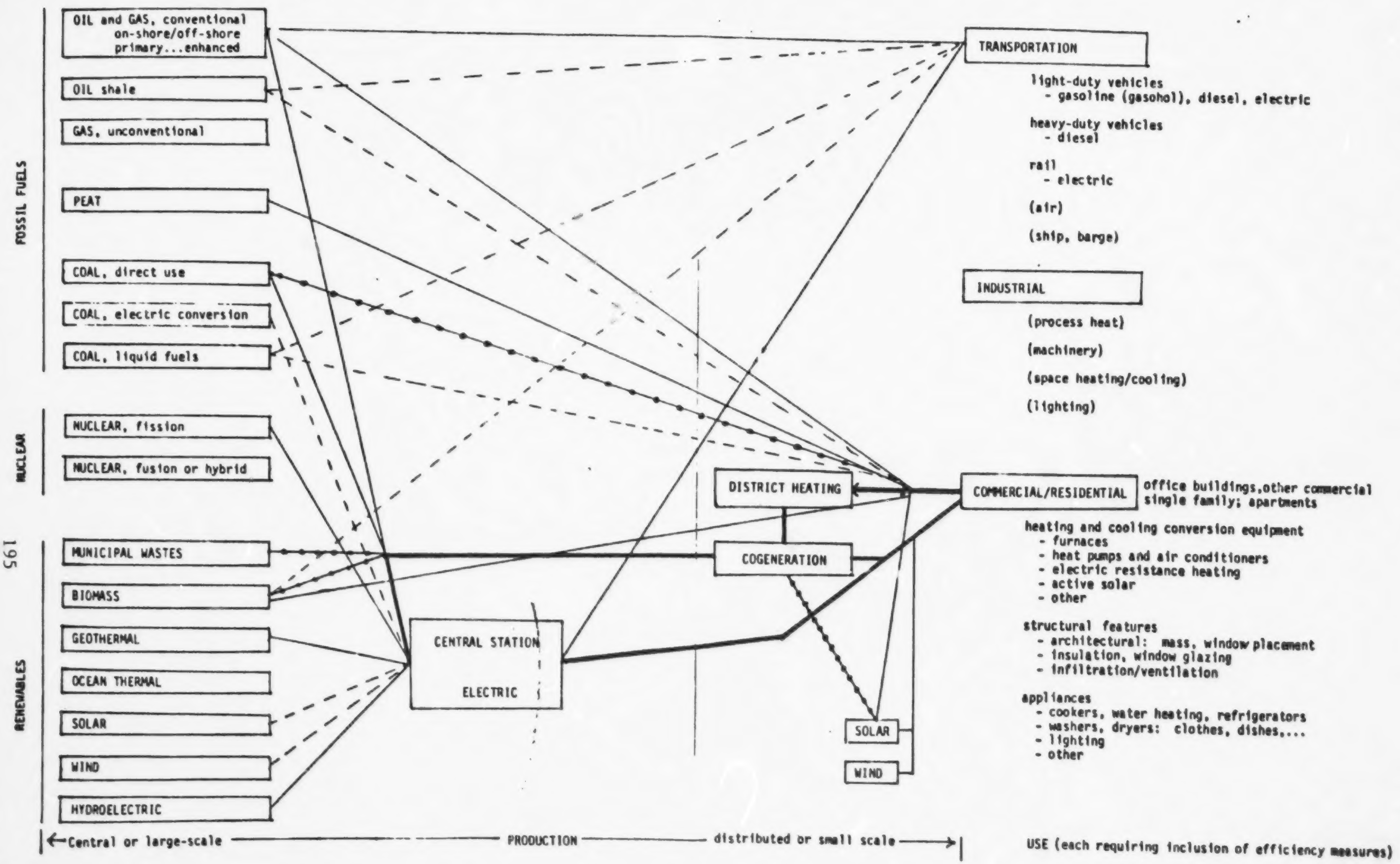
- CHANGES IN SOURCE STRENGTH (E.G., DUE TO CHANGES IN BUILDING TECHNOLOGY)
- CHANGES IN INFILTRATION OR VENTILATION RATE (DUE TO ENERGY CONSERVATION OR IAQ MEASURES)
- ACTIVE AIR CLEANING

MAJOR CONSIDERATIONS:

- MANY POLLUTANTS
- NEED EXPOSURES AND DOSE-RESPONSE FOR EACH
- CHANGES BOTH INDOOR AND OUTDOOR EXPOSURES
- HAVE TO EVALUATE BOTH POPULATION-AVERAGE AND INDIVIDUAL RISKS

A COMMON DIFFICULTY IN ANY SUCH EVALUATION IS TO PAY MOST ATTENTION TO THE RISKS THAT CAN BE QUANTIFIED AND TO IGNORE THE REST.

FIGURE 4: ENERGY SYSTEM


FOSSIL FUELS
OIL and GAS, conventional on-shore/off-shore primary...enhanced
OIL shale
GAS, unconventional
PEAT
COAL, direct use
COAL, electric conversion
COAL, liquid fuels
NUCLEAR
NUCLEAR, fission
NUCLEAR, fusion or hybrid
RENEWABLES
MUNICIPAL WASTES
BIOMASS
GEOTHERMAL
OCEAN THERMAL
SOLAR
WIND
HYDROELECTRIC
CENTRAL STATION ELECTRIC
DISTRICT HEATING
COGENERATION
SOLAR
WIND
TRANSPORTATION
light-duty vehicles
- gasoline (gasohol), diesel, electric
heavy-duty vehicles
- diesel
rail
- electric
(air)
(ship, barge)
INDUSTRIAL
(process heat)
(machinery)
(space heating/cooling)
(lighting)
COMMERCIAL/RESIDENTIAL
office buildings, other commercial
single family; apartments
heating and cooling conversion equipment
- furnaces
- heat pumps and air conditioners
- electric resistance heating
- active solar
- other
structural features
- architectural: mass, window placement
- insulation, window glazing
- infiltration/ventilation
appliances
- cookers, water heating, refrigerators
- washers, dryers: clothes, dishes,...
- lighting
- other
←Central or large-scale
PRODUCTION
distributed or small scale→
USE (each requiring inclusion of efficiency measures)

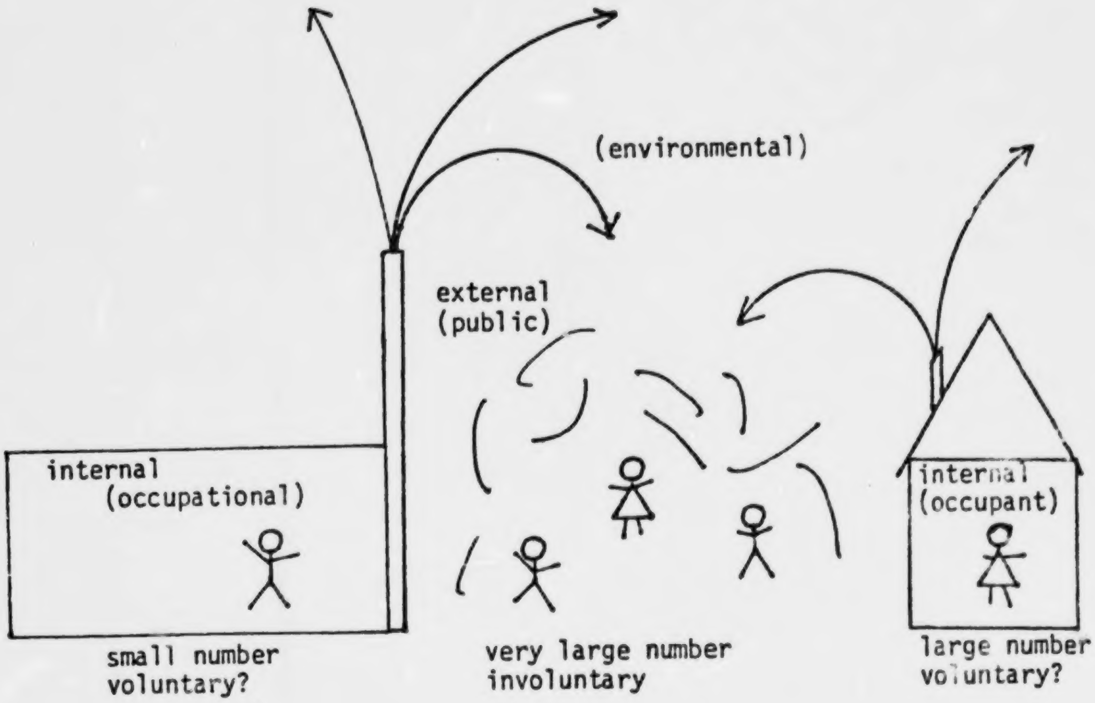

(environmental)
external
(public)
internal
(occupational)
internal
(occupant)
small number
voluntary?
very large number
involuntary
large number
voluntary?

FIGURE 3: CLASSES OF ENVIRONMENTAL EFFECTS

EXAMPLE

EFFECTS OF CHANGE IN INFILTRATION RATE?

RADON DAUGHTER EXPOSURES

- COMPLICATED IN ANY CASE
- DEPENDS ON MANNER OF IMPLEMENTATION

OTHER INDOOR POLLUTANTS

- NOT ALL IDENTIFIED
- RISKS USUALLY NOT QUANTIFIED

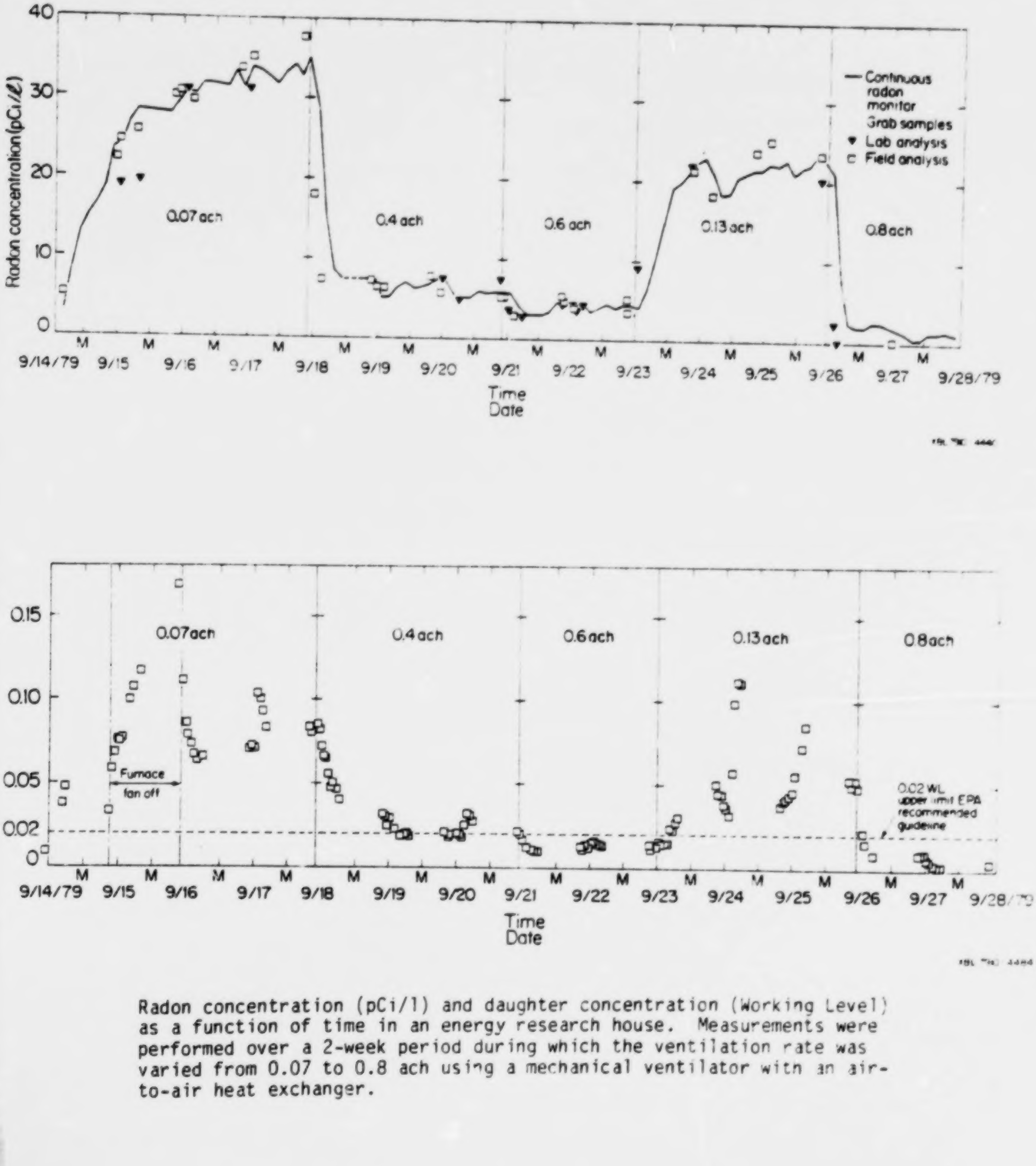
ASSOCIATED CHANGES IN OUTDOOR POLLUTION

- EFFECTS FROM CENTRAL STATIONS
- EFFECTS FROM LOCALLY GENERATED POLLUTANTS?

INDIRECT HEALTH EFFECTS

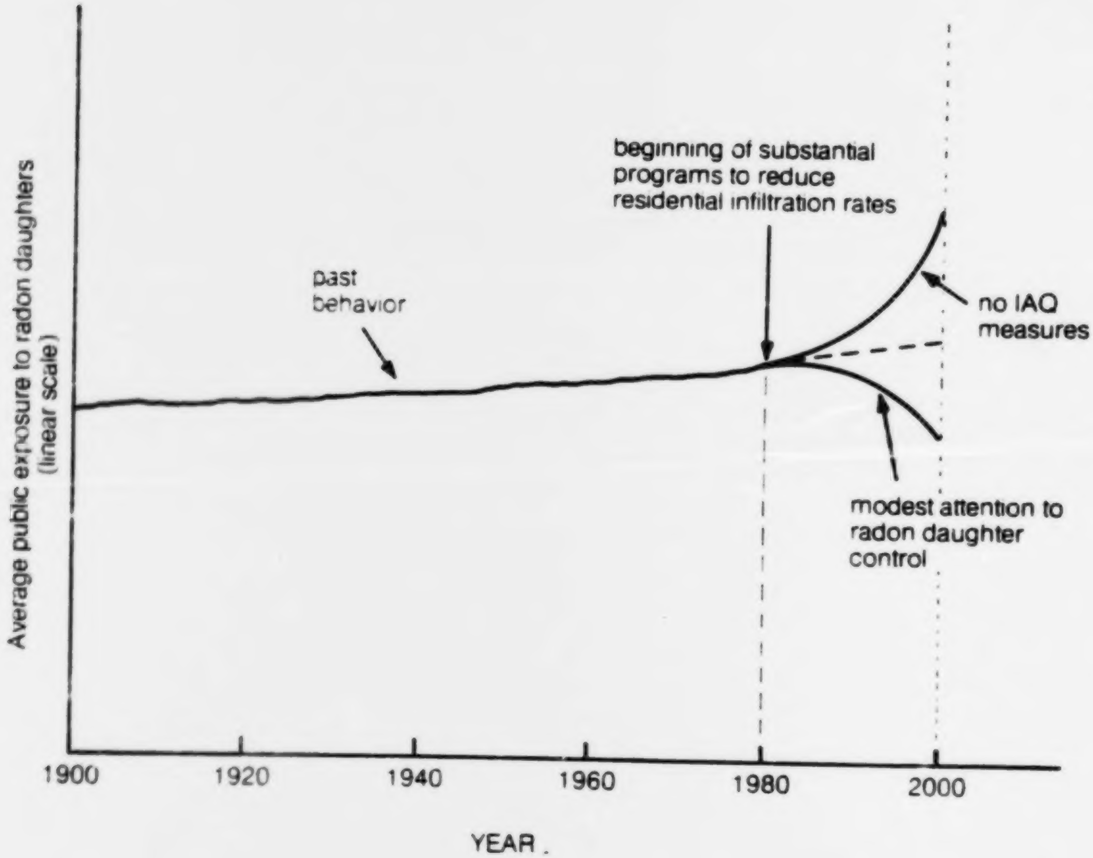
- OIL WAR?
- CO_2?

(MORE GENERAL ENVIRONMENTAL EFFECTS)



Radon concentration (pCi/l) and daughter concentration (Working Level) as a function of time in an energy research house. Measurements were performed over a 2-week period during which the ventilation rate was varied from 0.07 to 0.8 ach using a mechanical ventilator with an air-to-air heat exchanger.

ILLUSTRATION OF POSSIBLE TRENDS FOR PUBLIC RADON DAUGHTER EXPOSURES



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Monitoring Indoor Air Quality
Research Recommendations

Pollutant Group — Recommendation Title

AEROSOLS

1. Exposure to Respirable Particles
2. Tobacco Smoke
3. Asbestos
4. Aeropathogens

ORGANICS

1. Characterization Study of Tenax-GC
2. Sources and Concentrations of Organics in Residences
3. Organic Contaminants in Office Buildings
4. Organic Contaminant Emissions from Building Materials
5. Exposure Assessment
6. Analysis of Phthalates
7. Contamination from Home Pesticide Use
8. Differential PCB Levels in Residences
9. Nitrosamine Formation During Cooking
10. Nitrosamine Formation as a Function of Smoking
11. Sources of Nitro-organic Compounds
12. Nitrosamine Exposure in Vehicles
13. Assessment of Odor Complaints
14. Mutagenic Air Contaminants from Cooking

CRITERIA GASES

1. **Defining Human Exposure to CO**
2. **Pilot Study on NO_2 Exposure**
3. **Determine Total Human Exposure to both Short- and Long-Term NO_2 Concentrations**
4. Establish a Research House or Chamber to Determine Fate of Emissions from Combustion Sources
5. Assess Impact of Alternate Space Heating Systems (coal stoves, kerosene heaters) on Indoor Air Quality
6. Evaluation and Calibration of Monitoring Instruments for Application in Indoor Air Quality Studies - Chamber Study
7. Program to assess importance of CO_2 in crowded rooms and offices where energy conservation is being practiced.
8. Development and Evaluation of Simple Broad Spectrum Monitoring Methods to Detect Combustion Effluents in Indoor Air

RADON

1. Radon and Radon Daughter Behavior in the Indoor Environment
2. Short-term Radon Measurements
3. National Indoor Exposure to Radon and Radon Daughters
4. Radon Sources and Ground Transport

FORMALDEHYDE

1. Continuous (Real-Time) Instrumentation for Formaldehyde
2. Eight-Hour Dosimeter for Formaldehyde
3. Formaldehyde Measurement Protocol
4. Biological Methods Related to Formaldehyde Measurement

STATISTICS AND MODELING

1. Statistical Sampling Strategies
2. Exposure Monitoring Strategies
3. Exposure Models
4. Defining and Classifying Microenvironments
5. Indoor-Outdoor Numerical Models
6. Dynamic Infiltration Model
7. Statistical Design for National Characterization of IAQ
8. Monitoring Source Strengths
9. "Case Study" Evaluation of IAQ Monitoring Studies
10. Pollutants Emitted from Building Materials
11. Space Heaters
12. Ventilation
13. Retrofit Technology

RESEARCH RECOMMENDATIONS: AEROSOLS

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Exposure to Respirable Particles

OBJECTIVE:
(1) Determine population exposure to particles
(2) Determine source contributions to exposure

BACKGROUND/ RATIONALE: Recent studies indicate personal exposure to respirable particles is higher than ambient outdoor concentrations.

DESCRIPTION: Research effort should include:
(1) Time-motion studies of populations
(2) Determination of composition, mass, and size of particles
(3) Relative contributions of important indoor sources such as smoking and cooking

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

(1) Instruments are needed with increased sensitivity for shorter sampling times using low-flow pumps required for acceptable size & noise levels by subjects. The instruments should be capable of measuring mass, size, and chemical composition.

(2) Physical models of particle flow, reactions deposition rates, etc.

(3) "Sociological" models of personal behavior (Time-motion studies, commuting pathways, etc.)

PREVIOUS RESEARCH:

(4) Comprehensive models of personal exposures, capable of combining physical & sociological models with actual measurements.

(5) Inducements to ensure broad volunteer participation needed.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT:	Tobacco Smoke
OBJECTIVE:	To determine the role and function of tobacco smoke vis-a-vis other respirable aerosols.
BACKGROUND/ RATIONALE:	Initial research results suggest that indoor tobacco smoke is the dominant respirable aerosol in terms of human exposure. Moreover, tobacco smoke is a proven human carcinogen and respiratory toxicant.
DESCRIPTION:	Evaluate the importance of tobacco smoke as a constituent of respirable aerosols. Such an effort requires an understanding of the physical and chemical characteristics of the different components of the respirable aerosols. An analysis of the following parameters would seem to be necessary: concentrations, sources, size, composition, toxicity levels, ventilation.
INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:	Instrumentation is presently inadequate. Required is a small portable sampler that can determine mass, chemical composition, and size of tobacco smoke particles in home, office, and commercial environments.

PREVIOUS RESEARCH: Repace & Lowrey, Science

RESEARCH RECOMMENDATIONS: ORGANICS

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Asbestos

OBJECTIVE: To evaluate the sources and concentrations of asbestos

BACKGROUND/
RATIONALE: Information on indoor-outdoor asbestos relationships is limited by the measurement and analysis techniques currently available.

DESCRIPTION: Establish a research project to evaluate systematically the source distribution, integrity, and indoor-outdoor absestos concentrations in an urban area.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY: Need instrument to provide continuous fiber counts with size determination and, hopefully, with fiber identification.

PREVIOUS RESEARCH: GCA and Yale University - developing a fiber counting instrument based on light scattering of particles rotating in an electric field.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Aeropathogens

OBJECTIVE: To determine the types and amounts of aeropathogens in buildings

BACKGROUND/ RATIONALE: Little is known about the sources, concentrations, and half-lives of aeropathogens within buildings. It is assumed that the ventilation rate is the single most important parameter in determining exposure.

DESCRIPTION: Detect and evaluate the types, levels, and characteristics of aeropathogens in a sample of commercial and institutional buildings. The survey should include older structures as well as the newer energy-efficient ones in order to evaluate the role of differential ventilation.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Characterization Study of Tenax GC

OBJECTIVE: To establish the operational characteristics of Tenax GC

BACKGROUND/
RATIONALE: Tenax GC work still possesses considerable experimental uncertainties and variation between laboratories.

DESCRIPTION: Sampling trains (pumps, collector materials, etc.) absorption & desorption efficiencies, interferences, effects of storing and aging the sample, trap configuration, elution apparatus, and many other factors associated with the Tenax thermal desorption method of quantifying organics in the atmosphere need to be investigated and standardized.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH: See IAQ Workshop paper by F. Jarke "State-of-the-Art in Organic Vapor Monitoring."

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Sources and Concentrations of Organics in Residences

OBJECTIVE: To determine the sources for and the episodic emission levels of organics from household appliances and activities.

BACKGROUND/
RATIONALE: Development of a data base on organics in residential structures requires several basic research projects of this variety.

DESCRIPTION: Establish a monitoring project that will investigate episodic emissions from household appliances and activities including [illegible] ~~and~~ not limited to the following: woodburning stoves, fireplace, space heaters, cooking, printing, varnishing, refinishing furniture, waxing, and cleaning.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Organic Contaminants in Office Buildings

OBJECTIVE: To characterize the ambient air quality in office buildings.

BACKGROUND/ RATIONALE: Numerous complaints of poor indoor air quality have been registered by workers occupying new, tight office buildings. Investigations by various government agencies have frequently failed to identify the responsible etiological agent(s). The widespread use of synthetic materials in these buildings make organic contaminants prime suspects.

DESCRIPTION: A two part study is needed:

- Laboratory validation of a sample system based on the use of a solid sorbent must be completed.
- A sample set of problem office buildings (1-5) must be identified.

  The following information should be collected:

  - Ventilation rates before and after remedial action.
  - Occupant complaints before and after remedial action.
  - Organic contaminant levels before and after.
  - Sources of organic contaminants should be identified (e.g. building materials) and correlated with those found in the air.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Traditional sampling using charcoal tubes suffers from solvent desorption dilution and irreproducible results. Use of a solid sorbent for sampling, with subsequent analysis by thermal desorption, offers promise of greatly enhanced sensitivity.

PREVIOUS RESEARCH: Schmidt, H.E. et al. Trace Organics in Offices. LB October 1980.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Organic Contaminant Emissions from Building Materials

OBJECTIVE: To identify sources of organic contaminants emitted from building materials.

BACKGROUND/
RATIONALE: Many widely used interior construction products can emit organic contaminants including solvents, plasticizers and degradation products.

DESCRIPTION: Simple headspace analysis can be used to survey building materials to identify those that may pose the greatest problem in the indoor environment. Selected building materials can then be subjected to more exhaustive testing. This would include determining emission rates under atmospheric pressure and controlled ventilation rates (to establish whether there is an equilibrium between the free and bound species). Evaluation as a function of temperature and humidity should also be performed. The study would be most useful if done in conjunction with field studies of problem office buildings so that correlations of sources and measured air concentrations could be established.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH: R. Miksch, LBL

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Exposure Assessment

OBJECTIVE: To assess the correlation between breath analysis and possibly blood levels with ambient air concentrations.

BACKGROUND/
RATIONALE: A direct measurement of dose would be desirable to help select organics of highest priority to EPA, and also to use as a screening tool in determining geographic areas where exposure might be high.

DESCRIPTION: Individual human exposures to organics of interest would be determined by personal air quality monitors (Tenax cartridges) and concurrent measurements of the same organics in drinking water and food. Immediately following the exposure periods, breath & blood samples would be taken. Correlations between air, water, food, breath & blood levels would be sought.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY: Analytical protocols for breath and blood levels of volatile organics have recently been developed, but require validation by other laboratories.

PREVIOUS RESEARCH: Breath: B. Krotosynzki, ...

Blood: Peoples, et al ...

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Analysis of Phthalates

OBJECTIVE: To analyze phthalates and phthalate acid esters from automobile interiors.

BACKGROUND/ RATIONALE:

DESCRIPTION:

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Project cannot be undertaken until tests have demonstrated that phthalates are collectable and desorbable from Tenax G.C. or some other suitable sorbent.

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Contamination from Home Pesticide Use

OBJECTIVE: To assess the extent of contamination resulting from home pesticide use.

BACKGROUND/
RATIONALE: A large scale (10,000 homes) survey of home pesticide use will be conducted by EPA. Monitoring procedures should be coupled to the survey to maximize information derived from the effort.

DESCRIPTION: Establish a monitoring phase to the forthcoming survey of home pesticide use. Emphasis should be on the extent of the contamination created by the in-house pesticide use. A major component of the monitoring should be a body burden analysis.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY: Polyurethane Foam (PUF) is adequate for collecting many common home pesticides.

PREVIOUS RESEARCH: EPA (HERL-RTP) studies of several homes.
R. Lewis, HERL-RTP.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Differential PCB Levels in Residences

OBJECTIVE: To determine the sources and concentrations of PCB's in residential structures

BACKGROUND/ RATIONALE: Evidence suggests that PCB levels are higher in the kitchen than other parts of the house.

DESCRIPTION: Select a sample of homes and establish a monitoring network that will allow the characterization of PCB levels within each different part of the structure. An important part of this effort is the need to identify the varied sources of PCB's throughout the building.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Polyurethane Foam (PUF) appears to be the method of choice at present.

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Nitrosamine Formation During Cooking

OBJECTIVE: To determine the nitrosamine levels associated with cooking of food and an analysis of possible methods of control.

BACKGROUND/
RATIONALE: It is known that nitrosamines form during cooking, but little has been done to investigate concentration levels, different mechanisms of formation, and potential methods of control.

DESCRIPTION: Analyze the formation of nitrosamines during cooking by examining the following items:

(1) Concentrations generated by gas vs. electric ovens
(2) Concentrations generated by meats and other known greasy foods
(3) Concentrations that prevail during the use of vented vs. unvented appliances
(4) Types of filters that may control nitrosamine levels and lifetimes.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Nitrosamine Formation as a Function of Smoking

OBJECTIVE: To determine the concentration levles of nitrosamines in public areas where smoking is allowed vs. where smoking is prohibited.

BACKGROUND/ RATIONALE: Little is known about the contribution of smoking to the formation of nitrosamines.

DESCRIPTION: Establish a sampling procedure wherein several similar sized public areas that permit smoking and several that prohibit smoking can be monitored for nitrosamine formation and concentration levels.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Sources of Nitro-organic Compounds

OBJECTIVE: To determine the sources of nitrosamines and hydrazene in buildings, homes, etc. and assess the impact of these sources on IAQ.

BACKGROUND/ RATIONALE: Basic information about sources of nitrosamines and hydrazine and their impact is necessary in the formation of a data base for these indoor air pollutants. Nitrosamines are found in certain rubberized materials (such as indoor-outdoor carpeting and upholstery) in homes and automobiles. They are also formed during certain activities such as cooking with gas and passive and active smoking. Hydrazine may be formed in reactions occurring during washing clothes.

DESCRIPTION: Select a sample of different types of buildings (commercial, institutional, residential) and monitor the sources of nitrosamine formation in each. Ventilation rates must be analyzed carefully to determine their effect on concentrations and decay rates.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Nitrosamine Exposure in Vehicles

OBJECTIVE: To determine the extent of exposure to nitrosamines in transportation vehicles.

BACKGROUND/
RATIONALE: Recent EPA testing of autos has revealed a tendency for a direct relationship between temperature and nitrosamine concentration. More research of this variety is needed along with an extension to other modes of transportation.

DESCRIPTION: Vehicles representing the major classes of interior materials would be tested under various conditions to determine the materials and conditions of major importance regarding nitrosamine emission rates.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY: Adequate; GC, GC/MS or TEA analyzers.

PREVIOUS RESEARCH: Car interior nitrosamine testing at various temperatures by EPA/MVEL

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Assessment of Odor Complaints

OBJECTIVE: To establish a protocol for classifying and handling odor complaints; to determine the impact of outdoor odors on IAQ

BACKGROUND/ RATIONALE: Not all odor complaints derive from nuisance-type activities, but may be symptomatic of quite serious hazards as in the case of Love Canal.

DESCRIPTION: Review the complaints filed with appropriate regulatory agencies and select several to investigate further using site-specific monitoring.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Panels of experts appear to be capable of reproducible results.

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Mutagenic Air Contaminants from Cooking

OBJECTIVE: To determine the sources and concentrations of mutagenic contaminants derived from cooking.

BACKGROUND/ RATIONALE: Pyrolysis of protein is known to produce potent mutagens, and injestion. Recent evidence, however, shows that 90% (!!) of the mutagenic activity volatilizes in the air. Occupational studies of cooks reveals increased risk ratios for cancers. Cooking is a universal human activity and the population at risk is very large.

DESCRIPTION: Gas stove studies in which meals are cooked under simulated (or real) real life conditions are required. A number of extremely straightforward control techniques can then be evaluated, including spot ventilation (range hood), recommended cooking practices, and improved gas stove designs.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: A specific sampling and analysis methodology must be developed. A specific trapping agent has to be developed for sampling. Subsequent analysis can be by chemical means or the mutagenic activity can be determined directly by the application of the Ames test.

PREVIOUS RESEARCH: S.M. Rappaport *et al.* "Volatilization of Mutagens from Beef During Cooking." *Cancer Letters*. 8(1979), pp 139-145.

RESEARCH RECOMMENDATIONS: CRITERIA GASES

Research Needs for IAQ: Monitoring

Pollutant CO

Defining Human Exposure to CO

Name R. Ziskind

Tel. (213) 553-2705

or J. E. Yocom
(203) 563-1431

Instrumentation adequate?

✓ **Yes** **Describe preferred instruments or analytic methods**

Fixed station instruments and PEM's are available and, by and large, adequate. It would be important to add memory capability to PEM's including data logging. Breath analyzers are useful to a limited degree.

___ **No** **Describe what has to be done to provide adequate monitoring equipment**

It would be desirable from a cost standpoint to develop inexpensive passive detectors.

Extent of previous monitoring efforts

Institution or investigator Various

Describe the study briefly Some personal monitoring, home monitoring, and in-vehicle monitoring have been done.

Description of suggested monitoring effort

Rationale CO is likely to be directly related to tightening up the indoor environment. Currently, exposures are close to known health effects levels. Need is to develop the data base on personal exposure (activity patterns/activity exposure distribution) in order to be able to use fixed site station data and apply the ambient air quality standards more meaningfully.

Description CO is perhaps the most logical choice for a comprehensive personal monitorin study. Sources, of course, both inside the house and outside and this study can genuinely help answer the question of how much will energy conservation measures affect indoor air quality and perhaps affect health. It can direct relate to the question of quantifying the importance of indoor exposure vis-vis total. A high priority in this study design is to develop activity related exposure frequency distributions. Heavy accent should be placed on statistical study design and quality assurance procedures. Careful decision need to be made on the number of subjects, the frequency of observations on each subject, and the rationale of test site selection.

Duration Up to 3 Years **Funding Level** (~~per year~~) Total 1 1/2 to 2 M

Research Needs for IAQ: Monitoring

Pollutant NO_2 (Phase I)

Name F. Burman

Tel. (919) 541-2106
or J. E. Yocom
(203) 563-1431

Instrumentation adequate?

[✓ Yes] for NO_2 passive monitors

Describe preferred instruments or analytic methods

Palmes tubes for average NO_2 exposure. It may be desirable to modify them for sequential operation in relation to modules in activity pattern.

[✓ No]

Describe what has to be done to provide adequate monitoring equipment

Passive monitors needed for O_3 - Also semi-continuous or continuous monitors. Personal monitors needed for both NO_2 and O_3.

Extent of previous monitoring efforts

Institution or investigator TRC, GEOMET, LBL, Palmes, etc.

Describe the study briefly Various IAQ studies.

Description of suggested monitoring effort

Rationale Much is known about indoor NO and NO_2 in various types of structures in relation to outdoor and indoor sources. Further work is needed to establish total human exposure including in-vehicle. Because of NO conversion to NO_2 in presence of O_3, methods are needed for monitoring O_3 by passive and other monitors.

Description Assess existing data on Indoor/Outdoor NO_2 to estimate indoor exposures. Utilizing passive NO_2 monitors, establish total human exposure in relation to various activity patterns. O_3 should also be measured, but so far there are no passive monitors available. Analyze data to assess total human exposure as compared with NAAQS's. If problems are shown, Phase II (see next sheet) should be initiated. The needed instrumentation for Phase II should be developed even before completion of the Phase I effort.

Duration 6 months Funding Level (per year) $60,000

12/4/80

Research Needs for IAQ: Monitoring

- **Pollutant** NO, NO_2 (Phase II)

Determine total-Human Exposure to both Short- and Long-Term Exposures to NO_2

Name James Berk

Tel. (415) 486-4651

Instrumentation adequate?

___ Yes Describe preferred instruments or analytic methods

[✓ No] Describe what has to be done to provide adequate monitoring equipment

Portable NO_x instrumentation capable of giving real-time information is needed.

Extent of previous monitoring efforts

Institution or investigator DOE(LBL), EPA(GEOMET), TRC

Describe the study briefly Indoor studies have been done in ∿ 20 residential and a few office buildings.

Description of suggested monitoring effort

Rationale Short- and/or long-term health effects of NO_x may be significant. Health studies will shed light on this. The distribution of exposures (both long- and short-term) for the general population is required in order to estimate the severity of NO_x exposure problems.

Description Select a proper (well stratified, different appliance type) sample of people throughout the country to monitor the distributions of short- and long-term exposures, both in-house, in transit, and in the non-industrial workplace.

Duration 2 Years **Funding Level (per year)** $200,000

12/4/80

Research Needs for IAQ Monitoring

Pollutant NO, NO_2

Establish a Research House or Chamber to Determine Fate of Emissions from Combustion Sources

Name James Berk

Tel. (415) 486-4651

FTS 486-4651

Instrumentation adequate?

___ **Yes** **Describe preferred instruments or analytic methods**

✓ **No** **Describe what has to be done to provide adequate monitoring equipment**

Some indoor interference problems with NO_x instruments (e.g., ammonia from cleaning solutions). Other than that, EPA-approval instruments are sufficient.

Extent of previous monitoring efforts

Institution or investigator LBL

Describe the study briefly Has done some dispersion measurements in a rented house under controlled conditions.

Description of suggested monitoring effort

Rationale Understand the production, transport, interaction and fate of these pollutants indoors. Validate models, propose schemes for control, deduce impact of energy conservation strategies.

Description Establish a research house to study the fate of these combustion appliance emissions. Monitor concentrations throughout the structure as a function of time for various source strengths and air exchange rates with and without exhaust hood operation. This information will aid in exposure studies. Other pollutants (CO, CO_2) could be studied simultaneously.

Duration 2 Years **Funding Level (per year)** 250 K

12/4/80

Research Needs for IAQ: Monitoring

Pollutant SO_2, CO, CO_2, NO_2, NO, Particulate Matter

Assess Impact of Alternate Space Heating Systems (coal stoves, kerosene heaters) on Indoor Air Quality

Name J. E. Yocom

Tel. (203) 563-1431

Instrumentation adequate?

✓ **Yes** **Describe preferred instruments or analytic methods**

NO_x & SO_2 - Chemiluminescent, CO & CO_2 - NDIR

___ **No** **Describe what has to be done to provide adequate monitoring equipment**

Extent of previous monitoring efforts

Institution or investigator LBL

Describe the study briefly Some test chamber work on CO, NO & NO_2 emissions from kerosene heaters.

Description of suggested monitoring effort

Rationale With increased use of coal stoves and kerosene heaters for space heating in the Northeast, indoor/outdoor air quality studies should be carried out to determine impact of these devices on indoor air quality.

Description Select several (say 6) homes utilizing coal stoves and/or kerosene heaters for making simultaneous measurements of avove listed pollutants indoors and outdoors. Studies should include measurement of air exchange rate, meteorological variables, and other pertinent parametric measurements to be made during cold months (Nov.-April)

Duration 6 Months **Funding Level (per year)** $60 K

12/4/80

Research Needs for IAQ: Monitoring

Pollutant All Criteria Pollutants Gases

Evaluation and Calibration of Monitoring Instruments for Application in Indoor Air Quality Studies - Chamber Study

Name Frank Kabot

Tel. (919) 493-2741
or J. E. Yocom
(203) 563-1431

Instrumentation adequate?

[✓ Yes] **Describe preferred instruments or analytic methods**

All instruments likely to be used in IAQ or human exposure studies.

No **Describe what has to be done to provide adequate monitoring equipment**

Extent of previous monitoring efforts

Institution or investigator All workers in IAQ.

Describe the study briefly This had been done only to a limited extent by each of these workers.

Description of suggested monitoring effort

Rationale Instruments used for IAQ studies are usually those designed for outdoor studies. There is a need to determine their adequacy for IAQ measurements, especially in relation to possible interference from indoor pollutants (e.g., chlorine, ammonia, aerosols, etc.)

Description Set up chamber for known concentrations of pollutants for cross comparis of various instruments. Introduce other contaminants found in indoor atmospheres (e.g., chlorine, NH_3, high CO_2, etc.) to determine interferences. Develop new calibrations as required, and identify instruments not suitable for specific applications.

Duration 1 Year **Funding Level (per year)** $100,000

12/4/80

Research Needs for IAQ: Monitoring

Pollutant CO_2

Program to assess importance of CO_2 in crowded rooms and offices where energy conservation is being practiced.

Name J. E. Yocom

Tel. (203) 563-1431

Instrumentation adequate?

✓ Yes Describe preferred instruments or analytic methods

COL - NDIR

___ No Describe what has to be done to provide adequate monitoring equipment

Extent of previous monitoring efforts

Institution or investigator LBL

Describe the study briefly Studies of schools and some houses.

Description of suggested monitoring effort

Rationale CO_2 buildup can occur as a result of human accupancy and exhaust gases from combustion. There is a need to identify those scenarios which tend to maximize indoor CO_2 concentrations and determine their importance.

Description Identify potentially important scenarios (e.g., crowded public places, older buildings with poor air distribution) measure CO_2 levels at various locations along with ventilation data. Survey literature on CO_2 effects vs. concentrations.

Duration 1 Year Funding Level (per year) $100,000

12/4/80

Research Needs for IAQ: Monitoring

Pollutant CO and Other Reducing Gases
Development and Evaluation of Simple Broad Spectrum-Monitoring Methods to Detect Combustion Effluents in Indoor Air

Name Frank Belles

Tel. (216) 524-4990

or J. E. Yocom
(203) 563-1431

Instrumentation adequate?

? **Yes** **Describe preferred instruments or analytic methods**

Gas detector based on Foguchi sensor.

___ **No** **Describe what has to be done to provide adequate monitoring equipment**

Extent of previous monitoring efforts

Institution or investigator AGA Labs

Describe the study briefly Detecting leaky heat exchangers.

Description of suggested monitoring effort

Rationale A quick and dirty method of assessing presence of combustion contaminants in indoor AQ.

Description Carry out monitoring studies to determine pollutant responses and whether device could be used to screen out situations of extremely poor IAQ. If successful, run pilot field study to monitor a large number of homes (say 1000) representing those where there is the greatest potential for leaky furnaces.

Duration 1 Year **Funding Level (per year)** $100,000

12/4/80

RESEARCH RECOMMENDATIONS: RADON

RESEARCH NEEDS FOR MONIT[illegible] IAQ

SUBJECT: Radon and Radon Daughter Behavior in the Indoor Environment

OBJECTIVE: To determi[illegible]e behavior of radon and radon daughters indoors.

BACKGROUND/
RATIONALE: Development of the initial radon data base requires basic information about the overall behavior of the pollutant in question.

DESCRIPTION: Parameters to be measured include radon and radon daughter concentrations, infiltration/ventilation rates, radon daughter and particulate interactions and size distributions, removal processes, the effects of temperature, humidity, and particulate levels, and the effects of HVAC system operation and various control strategies.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY: Existing instrumentation except, perhaps, in daughter/particle interaction work, is sufficient for these studies.

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Short-term Radon Measurements

OBJECTIVE: To assess the viability of short-term radon measurements to estimate annual average concentrations and indoor exposures.

BACKGROUND/
RATIONALE: Detailed measurements for a one-year period such as the Butte, Montana study need to be supplemented by additional work at progressively larger scales.

DESCRIPTION: Measure radon and radon-daughter concentrations on a real-time and integrated basis, infiltration/ventilation rates, and radon fluz from the soil. Measurements should occur on real-time and integrated bases for a period of one year to determine the feasibility of and to establish protocols for shorter term integrated monitoring.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: National Indoor Exposure to Radon and Radon Daughters

OBJECTIVE: To determine the extent to which indoor radon and radon daughters are a national problem.

BACKGROUND/RATIONALE: A data base is necessary in order to make program decisions and to consider the need for guidelines and standards.

DESCRIPTION: Survey a sufficient number of homes in the U.S.to project the extent of the national level of indoor exposure to radon and radon daughters.

INSTRUMENTATION/METHODOLOGICAL ADEQUACY: Existing passive monitors for monitoring radon are currently being evaluated, but passive working level monitors are needed if working level measurements are deemed necessary.

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Radon Sources and Ground Transport

OBJECTIVE: To develop predictive capabilities for indoor radon and radon daughter concentrations.

BACKGROUND/ RATIONALE: By determining the relevant parameters that contribute to high indoor concentrations in residences and by understanding the mechanisms through which radon enters building spaces, houses can be constructed with lower indoor radon levels.

DESCRIPTION: Measurements must be made of radium content in soil, radon concentrations in soil gas, radon diffusion lengths, and the efforts of ground water and moisture, atmospheric pressure, and temperature. It is necessary to determine temporal variation in these parameters.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH RECOMMENDATIONS: FORMALDEHYDE

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Continuous (Real-Time) Instrumentation for Formaldehyde

OBJECTIVE: To support the on-going development of a continuous, real-time instrument for detecting formaldehyde in the indoor environment.

BACKGROUND/
RATIONALE: To be able to relate formaldehyde emissions to sources, a real-time continuous monitor capable of achieving levels as low as 30 ppb is required.

DESCRIPTION:

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Eight-Hour Dosimeter for Formaldehyde

OBJECTIVE: To design and construct an eight-hour dosimeter for detecting formaldehyde in the indoor environement.

BACKGROUND/RATIONALE: To measure personal exposure to formaldehyde is required.

DESCRIPTION: The dosimeter would give integrated 8-hour average values of formaldehyde levels. It could collect the gas and be analyzed later in the laboratory; real-time continuous readout capacity would not be required for this use.

INSTRUMENTATION/METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Formaldehyde Measurement Protocol

OBJECTIVE: To establish a measurement protocol for monitoring formaldehyde in the indoor environment.

BACKGROUND/ RATIONALE: As a major pollutant emitted by home insulation and other materials, and also because detection and analytical procedures are specific to it, formaldehyde deserves special attention.

DESCRIPTION: Select and evaluate a protocol for measuring formaldehyde as one constituent of IAQ. Simultaneous measurements of other pollutants that create similar symptoms must be a part of the research. In addition, round-robin multilaboratory techniques should be incorporated into the project.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Refinement of both sampling and analytical methods needed in the long term. Present NIOSH limit of 0.5 ppm should be lowered to about 30 ppb.

PREVIOUS RESEARCH: NIOSH protocols adequate for occupational exposure.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Biological Methods Related to Formaldehyde Measurement

OBJECTIVE: To investigate biological methods as a means of increasing the sensitivity of formaldehyde measurements.

BACKGROUND/
RATIONALE:

DESCRIPTION:

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH RECOMMENDATIONS: STATISTICS AND MODELING

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Statistical Sampling Strategies

OBJECTIVE: To provide statistical methods which can be selected as needed for data acquisition in support of epidemiological adequacy of control measures.

BACKGROUND/ RATIONALE: Although many statistical techniques exist that can be applied to IAQ, certain problems specific to IAQ required modified sampling and statistical strategies.

DESCRIPTION: The following specific statistical tools need to be developed:

1. Strategy to isolate true peak exposures
2. Strategy to identify amplitude distributions of exposures
3. Strategy to identify time history of exposures
4. Strategy to relate individual exposures to individual responses even in the presence of a latent period
5. Stategy to identify the most significant exposures for each individual (i.e., home vs. work vs. community vs. recreation)

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Statistics for integrated sampling are adequately described in NIOSH, but statistics for determining time histories, temporal correlations and peak exposures are not well investigated. Problem of correlating exposure to (time-dependent) response is not solved.

PREVIOUS RESEARCH: R.M. Tuggle (U.S. Army Env. Hygiene Agency), Steve Rappaport (U.C.- Berkeley), J.C. Roch (USAF/OEHL)- Examination of sampling environments without time correlation for average, peak and variability of exposures.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Exposure Monitoring Strategies

OBJECTIVE: To select efficient sampling strategies for exposure monitoring.

BACKGROUND/
RATIONALE: Few exposure monitoring studies have been carried out. The type and extent of exposure monitoring will vary according to study design. Different designs must be developed to satisfy different objectives. (e.g. long-term chronic exposure to low-level indoor pollutants vs. "episodic" monitoring for short-term peak exposures).

DESCRIPTION:

Design a research project that will consider the main types of studies related to exposure monitoring and evaluate the different sampling strategies associated with each. Both retrospective and prospective studies should be considered for acute and chronic health effects.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Exposure Models

OBJECTIVE: To determine population-weighted 24-hour exposure

BACKGROUND/
RATIONALE: Existing information about population mobility patterns and time budgets is obtained from sociological studies. Special effort must be made to develop questionnaires that deal specifically with indoor air quality topics.

DESCRIPTION: Formulate deterministic or statistical models that will estimate exposure to pollutants as a function of population, time budgets, activity patterns, environmental models and pollutant concentrations.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY: Existing models are not comprehensive, lacking information on indoor activity patterns, ranges of exposures characteristic of indoor environments, etc.

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Defining and Classifying Microenvironments

OBJECTIVE: To design and implement a research program leading to the establishment of acceptable categories of microenvironments

BACKGROUND/ RATIONALE: Previous measurements have shown that fixed monitoring stations do not adequately reflect human exposures. To estimate population exposures with greater accuracy, it is necessary to collect data on pollutant concentrations in selected microenvironments.

DESCRIPTION: Establish a research program that will lead to a realistic method for the establishment of microenvironments as required in studies designed to monitor differential exposures, assess health effects, and design controls. Develop a suitable statistical basis for identifying microenvironments.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

Ott,

PREVIOUS RESEARCH: O[illegible] W. "Concepts of Human Exposure to Air Pollution," SIMS Technical Report No. 32, July 1980, Stanford Univ.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Indoor-Outdoor Numerical Models

OBJECTIVE: To validate existing indoor-outdoor models

BACKGROUND/ RATIONALE: Existing models of indoor-outdoor relationships among air pollutants have not been tested or evaluated. Such models are required to extrapolate monitoring data to the major types of indoor environments.

DESCRIPTION: Identify all monitoring conditions under which the models must be validated. Define exact validation protocol and parameters, perform a sensitivity study, and establish needs for future monitoring.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Existing models have not been extensively validated.

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Dynamic Infiltration Model

OBJECTIVE: To evaluate the effect of energy conservation measures on the IAQ of a particular house and to extrapolate the results of an IAQ audit to a full year profile.

BACKGROUND/ RATIONALE: Little is known of effects of infiltration on IAQ. This is one module of an IAQ indoor-outdoor model.

DESCRIPTION: Develop an IAQ model for residences that has a dynamic infiltration component. The infiltration component would have imputs of wind degree days, house size and volume, a terrain factor, and the house air leakage area.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Statistical Design for National Characterization of IAQ

OBJECTIVE: To determine if IAQ is a potential problem on a national scale.

BACKGROUND/
RATIONALE: Several pilot studies have established a trend for potential problems.

DESCRIPTION: Design a statistically valid experiment to assess IAQ on a national scale. Design should include all parameters that affect IAQ and address cost-effectiveness issues. Elements to be included are: instrumentation; pollutants of interest; types of indoor environments; location; housing type; monitoring protocols; source characterization;

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Monitoring Source Strengths

OBJECTIVE: To develop a national IAQ profile of source strengths

BACKGROUND/
RATIONALE: Project should be part of the on-going effort to develop a comprehensive nationwide IAQ data base.

DESCRIPTION: Develop a data base to identify indoor pollution sources and the frequency distribution of source strengths for a particular class of houses (e.g., NO_2 emissions in houses with only gas stoves as an NO_2 source).

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: "Case Study" Evaluation of IAQ Monitoring Studies

OBJECTIVE: To develop a "case-study" method for evaluating monitoring projects.

BACKGROUND/ RATIONALE: To avoid repeating mistakes in monitoring IAQ, a mechanism should be developed whereby a particular monitoring project can be evaluated in terms of its success in meeting its research objectives.

DESCRIPTION: (1) Select already completed studies for a "case study" approach, or

(2) Incorporate into future studies a procedure to evaluate the cost-effectiveness of the study itself.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Pollutants Emitted from Building Materials

OBJECTIVE: To determine the types and amounts of pollutants emitted from building materials commonly used in the construction of enery-efficient structures.

BACKGROUND/
RATIONALE: Energy conservation measures reduce the air exchange rate of structures and potentially harmful concentrations of pollutants may be accumulating inside residential as well as commercial structures (sick buildings).

DESCRIPTION: Establish a monitoring program that will foster the procurement of a data base on the types and amounts of pollutants generated by building materials considered to be energy efficient. Measurements should be conducted for different temperature levels, air flow rates, and humidity levels.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Space Heaters

OBJECTIVE: To examine fugitive emissions from space heaters.

BACKGROUND/
RATIONALE: Increased usage of space heaters, some of new design, requires investigation of their possible effects on IAQ.

DESCRIPTION: Evaluate fugitive emissions on a temporal and operating function basis for solid, liquid, and gas felled space heaters.

INSTRUMENTATION/
METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Ventilation

OBJECTIVE: To develop: (1) a macro-scale data base to characterize USA building stock on an average basis, (2) a micro-scale data base to correlate real-time pollutant levels with other variables.

BACKGROUND RATIONALE:

DESCRIPTION: (1) Establish a monitoring program to obtain data bases useful for characterizing ventilation rate by building type, geographic location, life-style, operation of building, and observed "average" pollutant level by season.

(2) Establish a monitoring program to obtain a micro-scale data base for correlating air exchange rates with pollutant level, pollutant source generation rate, and physiological effects.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY: Both instruments available: 1) fan pressurization method for determination of air leakage rate, and 2) tracer gas decay method for determination of air change rate at a particular time.

PREVIOUS RESEARCH: LBL, Princeton University, and Ohio State University - studies (on limited number of buildings) correlating air leakage rate with air change rate and weather, and with pollutants level.

RESEARCH NEEDS FOR MONITORING IAQ

SUBJECT: Retrofit Technology

OBJECTIVE: To explore the feasibility of retrofitting as a partial solution to the IAQ problem.

BACKGROUND/ RATIONALE: Retrofitting will probably be the major mechanism to improve IAQ in already existing buildings. Current costs may hinder adoption.

DESCRIPTION: Assess and improve the engineering flexibility of retrofit technology. Ventilation rates and recirculate/make-up air heavily influence indoor concentrations, dosages, and energy use. Selective filtration and variable ventilation rates will be desirable technological characteristics.

INSTRUMENTATION/ METHODOLOGICAL ADEQUACY:

PREVIOUS RESEARCH:

Appendix C

STATE OF THE ART IN ORGANIC VAPOR MONITORING

STATE OF THE ART IN ORGANIC VAPOR MONITORING

The state of the art in Organic Vapor Monitoring has recently been reviewed by a group at UCLA and appeared in the October issue of The Journal of the Air Pollution Control Association, 30, 1098 (1980). This supplies extensive detail on the higher molecular weight hydrocarbons. Therefore, this section concentrates on the methods used for lighter molecular weight compounds.

While the use of adsorbents to concentrate ambient air vapors was first proposed in the mid 1960's, the state-of-the-art is still not as highly developed as one would expect.

Solid Adsorbents - Porous Polymers

The majority of the ambient air work has been done on porous polymers of various types. Activated carbon is by far the best adsorbent, but the compounds can only be removed quantitatively by solvent elution; this defeats the concentration effect by rediluting the compounds.

Of the porous polymers used to date, Tenax GC (2,6-diphenyl-p-phenylene oxide) embodies the most versatile set of properties. It has a fairly high collection efficiency in spite of a fairly low porosity compared to XAD resins and activated carbon. It has the highest thermal stability of any porous polymer allowing for thermal desorption at high temperatures (300°C) and it has fewer problems with artifact formation due to reaction of chemicals the resin or because of catalytic conversions.

---

[1] D.L. Brooman and E. Edgeley. Concentration and Recovery of Atmospheric Odor Pollutants Using Activated Carbon. J. APCA. 16,25 (1966).

[2] A. Dravnieks and B.K. Krotoszynski. Collection and Processing of Airborne Chemical Information. J. Gas Chrom. 1966,367 (1966).

[3] F.W. Williams and M.E. Unstead. Determination of Trace Contaminants in Air by Concentrating on Porous Polymer Beads. Anal. Chem. 40,2232 (1968).

Tenax GC adsorbs and desorbs an extremely wide variety of chemicals. The adsorption and desorption efficiencies have been studied for only a limited number of compounds, but in one laboratory, highly unstable (thermally) compounds have been collected and desorbed with little or no problems encountered.

Water vapor appears to have little or no effect on the use of Tenax GC as an adsorbent and this makes it ideal for atmospheric applications. Tenax GC also can be easily cleaned up and reused either by thermal means or by Soxhlet extraction.

The major difficulties in the use of Tenax GC as an adsorbent for trace organic vapors in air are: (1) trap configuration, (2) sampling train and its use (3) the dilution apparatus or technique.

Commercial systems for these aspects as yet do not widely exist. Nutech is the only commercial company that is routinely providing equipment specifically for this purpose and many of their users report that the equipment does present problems in its use. Hewlett-Packard provides an automated purge and trap system that can be used for these types of measurements but certain user modifications are necessary.

Trap Configuration

There are two versions of trap in common use: glass and metal. All chromatographers know that certain compounds containing reactive functional groups are chromatographed more clearly in glass columns than in metal columns; however, the process that is going on in a GC column may be entirely different than in a vapor preconcentration trap. Therefore, the controversy over glass versus metal ambient air collectors continues in spite of the success of at least two major laboratories--one using glass collectors, the other metal collectors. This question should be investigated in detail once and for all. The advantages and disadvantages of glass versus metal are summarized in Table 1.

TABLE 1. GLASS vs METAL COLLECTORS

Glass	Metal
ADVANTAGES:	
1. Packing is visible and can be inspected for deterioration.	1. Connectors assuring positive leak-free connections are more readily available. Most are bakeable.
2. Packing can be removed easily and cleaned-up externally for reuse.	2. Metal is rugged and withstands rough handling.
	3. Thermal desorption can be achieved by direct electrical resistance heating.
	4. No special shipping or storage containers needed.
DISADVANTAGES:	
1. Easily broken.	1. High initial cost.
2. Connections are difficult and not readily available.	2. Packing is not visible.
3. Higher risk of cross contamination from extensive use of Teflon closures and seals.	
4. No direct desorption capability.	

Sampling Train

Sampling trains are as numerous as the number of researchers working in the field. The only common element is that all use some form of vacuum supplied by a vacuum pump but from here all resemblance ends. The greatest discrepancies are (1) the method used to determine the volume of gas sampled (2) the method used to set and monitor the flow rate, and (3) the use or lack of use of a particle filter upstream of the sampling trap.

Two types of samples have been collected in using Tenax GC for ambient air sampling of volatile organic vapors. One technique is called integrated sampling and sampling periods of 12-24 hours are used with flow rates of 15-45 mL/min. A collector of approximately 2-3 grams of Tenax GC is used for this type of sample and breakthrough volumes of C_6 molecules are approximately 10-30 liters.

The second type of system is the grab sample which uses a sampling period of only one hour at 30-45 mL/min with final collected volume of approximately 2 liters. Only about 90-100 mg of Tenax GC are used in this mode.

The limit of sensitivity in the grab sample mode is about 0.5 ppb vol/vol for decane, and in the integrated mode, about 30-40 ppt.

Elution Apparatus and Techniques

The most difficult aspect of this type of analysis is achieving reliable and quantitative transfer of the collected vapors to the GC or GC/MS. Once they have been transferred the analytical techniques are well defined and perfectly suitable for this type of analysis.

The grab sample method is the only system employing Tenax GC that allows for reproducibile, quantitative thermal desorption of the preconcentrated vapors directly into a capillary or packed column at room temperature with no cryogenic focussing or other conditioning steps.

All systems for integrated samples require a cryogenic step preceding injection into a gas chromatograph. The problem with these systems is to ensure that compounds are not lost in the cryogenic step. This can happen if (a) the trap and cryogenic system does not trap all compounds, (b) the system leaks or does not adequately transfer the vapors from the trap to the cryogenic loop and (c) the trap is blocked by water vapor, resulting in the cessation of flow and inadequate transfer.

Using internal standards is the most effective way to determine trapping and transfer efficiency, but these methods suffer from a lack of effective means for transferring known quantities of standard onto the trap without disturbing the collected sample or in a reproducibly quantitative manner. Methods that have been tried are direct liquid injection, permeation tubes, and flash evaporation in a flowing air stream.

The actual desorption over any length of time as well as temperature can greatly effect the reproducibility in the transfer step. The greater the diameter of the collector the longer it takes to heat the Tenax GC at the enter of the bed and some data indicates it may be as much as 100°C lower in temperature.

Another potential problem area with Tenax GC is artifact formation through reactions with atmospheric constituents such as NO_2 and O_3. Benzene is frequently mentioned as a contaminant but whether it comes from the Tenax or the cleanup method is unclear.

Shelf life is an unknown aspect of this tenchique. How long after a sample is collected should it be used? The lack of adequate methods for putting known quantities on Tenax makes it difficult to determine this aspect. How long can a collector sit around before use? The larger diameter collector seems to have more of a problem with this than the smaller diameter collectors. This may come from inadequate desorption.

A thorough study of all aspects of the Tenax GC method and standardization must be achieved to ensure that data collected during the IAQ study is accurate and meaningful.

The recent contractor's comparison held at Love Canal by the EPA indicates that with nine different labs participating the results can vary over a wide range. This variation stems from the nine different sets of sampling trains, collector configuration, and desorption apparatuses. Even when labs use the same equipment the results can differ markedly.

With proper care and attention to details the results may be reproducible within ±10-15%; however, this level of precision should be adequate enough to determine the extent to which organic vapor contamination in homes differs and its relation to occupant health, safety, and comfort.

Selecting a Dust Monitor

Type of Information Desired:

- Relative or Quantitative Concentrations
- Periodic or Continuous Monitoring
- Alarm Function
- Dust Source Detection
- Filter Efficiency or Breakthrough
- Range of Dust Concentrations
- Size Distribution Measurements

Types of Dust - Important Parameters

Dust & Environmental Parameter	Relevant Instrument Parameter
1. Size Distribution	- Type of Preselector - Inlet Losses - Detection Principle - Collection Mechanism (if any)
2. Refractive Index and Density (affects light scattering instruments only)	- Detection and Calibration
3. Aerosol Phase (Solid/ Liquid/Vapor)	- Detection Principle - Collection Mechanism (if any)
4. Particle Shape	- Detection Principle
5. Humidity	- Detection Principle - Collection Mechanism (if any)
6. Temperature	- Electronic Drift - Detection Principle - Battery Output

Direct Reading Portable

Field Instruments

The following information is intended only as guideline to give the reader a feeling for the relative merits of each instrument in terms of cost and field usage. For more comprehensive or up-to-date information, contact the manufacturer or a current user of the instrument.

Tyndallometer T.M. Digital

Manufacturer: Leitz, Germany
Distributor: Preiser/Mineco,
St. Albans, W. Va.

Operating Principles: Forward (70°) light scattering, LED light source, passive sampling.
Size: 26 x 27 x 6.5 cm
Weight: 3.5 kg
Cost: $10,000.

Separate Battery Pack

Size: 25 x 17 x 10 cm
Weight: 4 kg
Cost: $1,250

Field Maintenance and Operation:

- Zeroing requires a separate pump to clear the air in the sampling chamber.
- Calibration requires insertion of a separate reference scatterer.
- Sampling is achieved passively through an 8 cm hole through the case.
- Depending on length of use and dust concentration, the light traps have to be replaced.
- The instrument can operate for about 9 hours on its separate NiCad battery pack.
- Readout is by Light Emitting Diodes
- The instrument time constant is about 15 sec.
- There is a voltage level indicator for monitoring battery condition.

Applications:	The T.M. was designed to monitor in German coal mines and is available in an intrinsically safe version. It will respond to virtually all types of dusts.
Advantages:	Samples passively Rapid response Easily operable
Disadvantages:	No respirable dust preselector. Bulky when used with battery pack. Needs calibration for different dusts. Zero and calibration checks are not readily performed. Optically critical surfaces are not protected from gradual contamination.

SIMSLIN

Manufacturer: Rotheroe and Mitchell,
United Kingdom

Distributor: Clasrock,
Atlanta, Georgia

Operating Principle: Forward light scattering laser diode light source, pump flowrate 0.625 LPM, horizontal elutriator preselector, digital memory, internal filter for calibration

Size: 4 x 11 x 15 cm

Weight: 7 kg

Cost: about $15,000

Field Maintenance and Operation:

- No field calibration.
- Self adjusting for light source level changes.
- Indicate low battery level and other malfunctions.
- The SIMSLIN must be placed in a horizontal position for preselector to work properly.
- The output is indicated in mg/m^3 and is fairly accurate for some common dusts such as coal, limestone and quartz.
- The digital memory records one data point every 15 seconds.
- Operation time on NiCad batteries is up to 30 hours.
- There are two Liquid Crystal Displays, one on the back and one on the side. There are several LED warning lights.

- The instrument time constant is 30 seconds.

Applications:

The SIMSLIN was designed for use in British coal mines and meets requirements for operation in explosive environments. It should be applicable to virtually all types of dusts and fumes. The preseparator is not removable so only respirable dust (according to BMRC curve) can be measured. The digital memory allows dust concentration vs time data to be recorded in the field and played back in the laboratory. The manufacturer's indicated two ranges of operation are 0.1 to 200 mg/m^3 and 0.01 - 20 mg/m^3.

Advantages:

Rapid response
Easily operable
Portable
Has data storage capacity
Long operation period (more than one day)
Intrinsically safe for explosive atmospheres
Internal filter sample available for calibration purposes.

Disadvantages:

Needs calibration for each type of dust (refractive index and size distribution)
No reference or secondary calibration check available.

Real Time Aerosol Monitor RAM-1

Manufacturer: GCA/Technology, Bedford, Mass.

Operating Principles: Near forward light scattering, pulsed IR Light Emitting Diode light source, pump flow rate 2 LPM (variable), clean air sheath over optics, 10 mm cyclone preselector.

Size: 20 x 20 x 20 cm
Weight: 4 kg
Cost: approx. $5,000.

Field Maintenance and Operation:

- An internal reference scatterer can be inserted for field calibration.
- For humid atmospheres (90% RH) the dessicant cartridge may need occasional replacement
- Two filter cartridges protect the pump. These need replacement depending on sampling time, dust concentration and size of aerosol particles. Fumes will clog the filters more rapidly than coarser dust.
- Operation time on NiCad batteries -- 6-8 hours.
- Has battery voltage indicator.
- The Liquid Crystal Display readout is updated at 0.3 second intervals with selectable time constants of 0.5, 2, 8 and 32 seconds. The time constant is selected to optimize sensitivity, response time and readout stability.
- The RAM-1 has a removable 10 mm

	nylon cyclone on the inlet. Total dust can be measured, but calibration may be difficult. - Manufacturer indicated range of operation 0.001 mg/m3 to 200 mg/m3 in three selectable ranges.
Applications:	The RAM-1 was originally developed to measure respirable coal mine dust. A version is available that is safe for explosive atmospheres. The RAM-1 will respond to virtually all kinds of aerosols.
Advantages:	Rapid response Clean air sheath on optics for good long-term stability Easily operable Minimal maintenance Output for analog recording Direct readout in mg/m^3
Disadvantages:	Needs calibration for each type of dust (size distribution and refractive index).

Fibrous Aerosol Monitor FAM-1

Manufacturer:	CCA/Technology, Bedford, Mass
Operating Principles:	Right angle light scattering, electrostatic alignment and rotation of fibers, HeNe laser light source, pump flowrate 2 LPM (nominal).
Size:	53 x 35 x 17 cm
Weight:	12.5 kg
Cost:	$10,000

Separate Battery Pack BP-FAM

Size:	31 x 13 x 17 cm
Weight:	7 kg
Cost:	$500
Field Maintenance and Operation:	- Field calibration not available. - Field checks of flowrate, laser beam alignment, electrostatic field level, dust scattering level and battery level available. - Normally line operated, but battery pack, BP-FAM available. - Internal filter cartridge may be used for approximate calibration. - The Liquid Crystal Display indicates fiber count continuously. Concentration in fibers/cc is indicated at selectable periods of 1, 10, 100, or 1000 minutes - The instrument operates up to to 4 hours on the battery pack.

Applications:	The FAM-1 was designed to measure asbestos aerosol concentrations and give results equivalent to the standard method. Fibers other than asbestos will also be detected. Fibrous glass may not be detected in dry (<30% RH)) atmospheres. Manufacturer's indicated range of operation 0.0001 - 30 fibers/cc.
Advantages:	Only available direct reading portable instrument for asbestos and other fibers. Rapid response.
Disadvantages:	Requires calibration for different types of fibers. Responds to fibers other than asbestos. Responds to elongated dust particles. Laser beam alignment sensitive to rough handling of the instrument (corrected on latest version)

Digital Dust Indicator Model P-5

Manufacturer: Sibata, Japan

Distributor: MDA Scientific, Chicago, Illinois.

Operating Principle: Right angle light scattering, tungsten lamp light source, pump flowrate 1 LPM, labyrinth type preselector corresponding to BMRC respirable dust curve.

Size: 20 x 18 x 8.4 cm
Weight: 3.5 kg
Cost: $2,000

Field Maintenance and Operation:

- Zero is set by placing a filter on the inlet.
- An internal reference scatterer can be inserted for field calibration.
- The labyrinth preselector needs occasional cleaning depending on measurement time and dust concentration.
- Operation time on NiCad batteries about 8 hours.
- The Liquid Crystal Display output is selected on a 0.1, 1, 2, 5, or 10 min or continuous interval. A convential meter also indicates the concentration. The concentration is indicated by a count that is proportional to the light scattering signal. One count/min indicates 0.01 mg/m^3 of 0.3 μm stearic acid particles.
- The labyrinth preselector can be removed for total dust sampling but calibration may be difficult.

Applications:	The P-5 is designed to meet Japanese requirements for measuring workplace air standards. It should be applicable to virtually all dusts and fumes. A higher sensivity version of the instrument is available. The manufacturer's indicated range of operation is 0.01 - 500 mg/m^3. (0.3 μm stearic acid)
Advantages:	Rapid response. Easily portable. Easily operable. Minimal maintenance.
Disadvantages:	Needs calibration for each type of dust (size distribution and refractive index). Critical optical surfaces not protected from gradual contamination.

Respirable Aerosol Photometer Model 5130

Manufacturer: NKK (Kanomax), Japan

Distributor: Thermo Systems, Inc. (TSI), Minnespolis, Minnesota

Operating Principle: Right angle light scattering, tungsten lamp light source, pump flowrate 4 LPM. 10µm cut size impactor preselector.

Size: 31 x 13 x 17 cm

Weight: 4 kg

Cost: $2,800

Field Maintenance and Operation:

- Zero is set by placing a filter on the inlet.
- An internal reference scatterer can be inserted for field calibration.
- The impactor preselector needs occasional cleaning and regreasing depending on measurement time and dust concentration.
- Operation time on NiCad batteries about 6 hours.
- Has battery voltage indicator.
- The LED readout is on a one minute or operator selected period. The concentration is indicated by a count that is porportional to the light scattering signal. One count/min equals 0.01 mg/m^3 0.3 µm stearic acid particles.
- The 10 µm impactor can be removed for total dust sampling. Inlet losses for larger particles may be significant and calibration may be difficult.

Applications:	The Model 5150 is designed to meet Japanese requirements for measuring workplace air standards. The manufacturer's indicated range of operation is 0.01 - 100 mg/m^3 (0.3 μm stearic acid).
Advantages:	Rapid response. Easily portable. Easily operable. Minimal maintenance. Moderate cost.
Disadvantages:	Needs calibration for each type of dust (size distribution and refractive index). Critical optical surfaces not protected from gradual contamination.

Portable Continuous Aerosol Monitor (PCAM)

Manufacturer: ppm, Inc.
Knoxville, Tennessee

Operating Principles: Near forward light scattering, Light Emitting Diode light source, separate detection channel for large particles, nominally 1.85 LPM flowrate, optional vertical elutriator preselector, 10 period memory.

Size: 41 x 23 x 20 cm
Weight: 9 kg
Cost: $7,500.

Field Maintenance and Operation:

- Provides automatic rezeroing and calibration.
- Requires purchase of separate lead acid battery and inverter for remote operation. Primarily designed as a 115 VAC line operated instrument.
- Has one minute stand-by battery in case of temporary line failures.
- Has continuous LED display with instrument time constant of about 4 sec.
- Has 10 memory locations in microprocessor controller. This allows instrument to operate for 10 user selectable periods of 0.25, 2, or 8 hours and retain total scattering and large particle fraction data.
- Manufacturer's indicated range of operation: 0.005 - 20.0 mg/m^3.

- PCAM has a removable horizontal elutriator, so total dust can be measured.

- Has an internal filter that protects the pump and allows instrument calibration.

Applications: PCAM was originally designed to measure cotton dust. By installing a 10 mm nylon cyclone, other types of respirable dust can be measured. The sensor will respond to virtually all types of dust and fume. The large particle fraction data allows better calibration under changing size distribution conditions. The automatic zero calibration and data logging allows extended unattended data accumulation.

Advantages:
Rapid response.
Auto zero and calibration.
Easily operable.
Minimal maintenance.

Disadvantages: Needs calibration for each type of dust (size distribution and refractive index).

TSI-3500 Piezo Balance

Manufacturer: TSI Incorporated,
St. Paul, Minnesota.

Operating Principles: The TSI-3500 is a portable aerosol measuring instrument that employs the principle of piezo-electric mass measurement. The aerosol particles are collected by an electrostatic precipitator onto an oscillating quartz crystal and the frequency of oscillation is changed by the collected mass. The instrument operates at 1 LPM with an optional 3.5 μm impactor preselecter. Without the impactor, a measurement of total dust can be made.

Size: 61 x 13 x 15 cm
Weight: 5 kg
Cost: $3,850.

Operation:

The instrument power is turned on and the chk button is depressed. The battery voltage is checked and then the STRT button is pressed to check the crystal frequency. If the crystal frequency is more than 1000 Hz above the clean crystal frequency, the crystal must be cleaned. After the crystal is clean the Meas. button is pressed. The precipitator current is checked and then the measurement is started by depressing the STRT button. After a preset period of time, the concentration in mg/m^3 is indicated on a digital display. Two different measurement times of 120 seconds and 24 seconds may be chosen. If the 24s time is used, the indicated concentration must be multiplied by 5 by the operator.

Range: $.1\ mg/m^3 - 20\ mg/m^3$

Maintenance:

Batteries must be charged prior to use. The instrument will operate for at least 8 hours on fully charged batteries. The crystal must be cleaned after approximately 5 - 20 readings depending on dust concentration using the built in cleaning mechanism. The cleaning operation requires about 5 minutes to perform. The cleaning mechanism has sponges that must be wetted before use and the sponges must be cleaned periodically. The precipitator must also be cleaned about once a week or whenever the current is low.

Applications: The instrument performs best with aerosols less than 5μm. Some aerosol where it has been applied are metal fumes, coal, silica, and fibrous glass. Some materials such as liquids and chained particles (e.g. carbon black) do not couple well to the measurement crystal and are detected with reduced sensivity.

Advantages: The instrument is portable, easy to use and responds directly to collected mass.

Disadvantages: The instrument does not respond well to aerosols with large particle sizes (> 5 μm).
Crystal must be cleaned periodically and this operation requires about five minutes.
The instrument cannot be used in explosive atmospheres.
The instrument does not respond well to liquids and particle chains.

RDM-101

Manufacturer: GCA Technology,
Bedford, Mass.

Operating Principles: The RDM-101 (Respirable Dust Monitor) is a portable dust instrument employing the principle of β-attenuation. The dust particles are impacted onto a thin grease coated plastic film where the mass of the deposit is measured by β-attenuation. The instrument can be used at 2 LPM with a 10 mm cyclone to obtain a mesurement of respirable dust and without a cyclone to obtain a measurement of total dust.

Size: 23 x 9 x 18 cm (without cyclone)
Weight: 3 kg
Cost: $4,690

Operation:

A clean collection substrate area is rotated under the impaction nozzle and the instrument is turned on. The measurement is started by depressing a Start switch. After a preset period of time, the measured concentration in mg/m^3 is indicated on a digital display. There are several different instruments available with preset measurement times of .2, 1, 4 and 8 minutes. The instrument may also be used in a semi-manual mode by placing start switch in a downward position after the measurement period is commenced. This allows the measurement period to be extended, but the operator must keep track of sampling time and calculate the concentration.

Range: .06 - 200 mg/m^3 (depending on measurement time.)

Maintenance:

The batteries in the instrument should be charged for 14 hours before use. Approximately 200 - 1 minute measurements can be taken with a fully charged instrument. The impaction substrate disc needs to be replaced after all the impaction areas are used up. There are 95 areas available on each disc. The instrument must be calibrated periodically using a factory supplied calibration disc. The calibration disc is put into the instrument in a specified position instead of the collection disc. A measurement cycle is started and the disc is advanced manually at a specified time. The reading can be adjusted with a potentiometer on the side of the instrument.

Applications: Since the instrument uses an impaction principle for collection of the dust on the collection substrate, the instrument will not collect particles smaller than about 0.7 µm. The instrument has been used for coal, fibrous glass, silica, and Arizona road dust.

Advantages:

The instrument is portable and easy to use.
The instrument responds directly to collected mass.
The instrument is intrisincally safe.

Disadvantages:

Instrument will not collect particles less than about 0.7 µm.
Not for use with fumes or liquid aerosol.
Collection substrate discs must be cleaned and coated after every 95 measurements.
The aerosol concentration must remain relatively constant during the measurement period if only a single measurement is performed.

RDM-201

Manufacturer: GCA/Technology,
Bedford, Mass.

Operating Principle: The RDM-201 (Respirable Dust Monitor) is a portable mass measurement instrument employing the principle of β-attenuation. The aerosol particles are collected on a high efficiency glass fiber filter where the mass of the collected dust is measured by β-attenuation. The instrument cam be ised at 2 LPM with a 10 mm nylon cyclone to obtain a measurement of respirable dust and without a cyclone to obtain a measurement of total dust.

Size: 23 x 9 x 18 cm (without cyclone)
Weight: 3 kg
Cost: $4,800.

Operation:

A clean filter is mounted in the instrument and the instrument is turned on. The measurement is started by depressing a Start switch. After a preset period of time, the collected mass in mg is indicated on a digital display. The operator must then calculate the concentration in mg/m^3. The instrument can also be used in a semi-manual mode by placing the Start switch in a downward position after the measurement period has commenced. This allows the measurement period to be extended but the operator must keep track of the sampling time and calculate the concentration.

Range: $.2\ mg/m^3 - 150\ mg/m^3$ sampling time must be extended to obtain accurate measurements at lower concentrations.

Maintenance:

The batteries must be charged prior to use. The instrument will perform for five hours on fully charged batteries. The instrument must be calibrated periodically using a factory supplied calibration disc. A measurement cycle is started and the calibration disc is put into the instrument after a certain period of time. The reading can be adjusted using a potentiometer on the side of the instrument.

Applications:	Coal dust Fiber glass Fumes
Advantages:	Instrument is portable, easy to use, and responds directly to collected mass. The instrument can measure particles less than 1 μm.
Disadvantages:	The instrument needs a fairly long measurement time to obtain accurate readings at lower concentrations. The instrument does not calculate the concentration directly. The filter must be changed periodically, or after each measurement.

RDM-301

Manufacturer: GCA Technology,
Bedford, Mass.

Operating Prinipcles: The RDM-301 is an automated version of the RDM-101 and employs the same operating principles.

Size: 46 x 33 x 28 cm
Weight: 19 kg
Cost: $11,900 (with battery pack)

Operation:

A clean collection substrate disc is mounted in the instrument. The instrument power is turned on and a measurement cycle is started by depressing a Start button. After a preset amount of time the collected mass in mg and concentration in mg/m^3 is printed on a tape. The measurement time is adjustable by use of a thumbwheel. The instrument may be operated in a single measurement mode where the operator initiates each measurement or in a continuous mode where the instrument proceeds automatically to the next measurement cycle. The results are printed so that there is a record of the concentration measurements as a function of time.

Range: .01 - 75 mg/m^3

Maintenance:

The batteries in the instrument must be charged prior to use. The instrument can operate for up to eight hours of continuous use without recharging the batteries. The impaction substrate disc must be cleaned and regreased when all the 495 impaction areas are used up. The instrument must be calibrated periodically using a factory supplied calibration disc. The instrument must be disassembled if the calibration requires adjustment. This adjustment is made using some BCD switches in one of the boards in the instrument.

Application: See RDM-101 write up.

Advantages: The instrument is fully automated and responds directly to collected mass.

Disadvantages: The instrument is not easily portable. (See RDM 101 write up for other comments.)